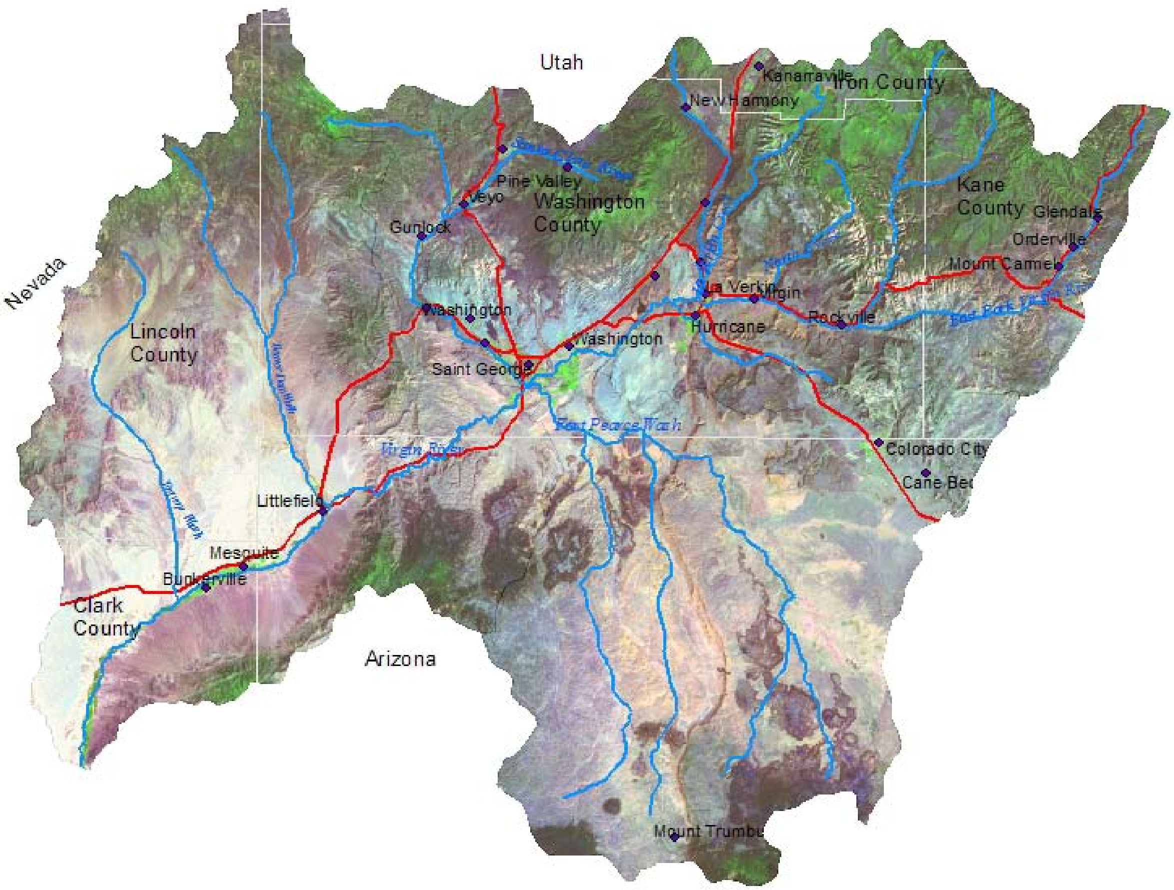
VIRGIN RIVER WATERSHED
Comprehensive Watershed Analysis
Utah, Arizona & Nevada



WATERSHED STRATEGY
October 2008

US Army Corps of Engineers

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EXECUTIVE SUMMARY

The 2006 Energy and Water Development Appropriations Act (PL 109-103) directed the Secretary to conduct, "*at full federal expense, comprehensive analyses that examine multi-jurisdictional use and management of water resources on a watershed or regional scale*". This study is one of five federally funded watershed studies being conducted in response to that legislation.

In carrying out this analysis, the U.S. Army Corps of Engineers is working in partnership with local and county governments, tribal, state and federal agencies, municipalities, landowners, citizen groups and the public. The goal of the analysis is to produce a watershed plan that assists stakeholders in successful management of the Virgin River and tributaries and related resources.

Watershed: The Virgin River's headwaters are in Washington, Kane, and Iron Counties of Utah and the lower watershed includes portions of Mohave County, Arizona and Clark and Lincoln Counties, Nevada. The river eventually empties into the Colorado River at Lake Mead in southeastern Nevada. Major tributaries to the Virgin River include the Santa Clara River, Fort Pearce Wash, and Beaver Dam Wash. Approximately 85% of the watershed is in public ownership, although the watershed is within a rapidly growing portion of the country.

Issues: Through coordination with stakeholders the key issues in the watershed have been defined. The top five issues within the watershed include: floodplain management, land use planning, invasive species, water availability, and river function. These issues are all interrelated, and to some extent overlap. There are several ongoing activities throughout the watershed, including those that address some of these issues. Review of over sixty reports confirms these five major issues and also areas where additional effort is needed. Several common themes pertaining to all of the identified issues have also been identified. They include the following:

- Communication and cooperation needs improvement.
- Need for useful tools and information to improve watershed management.
- Borders and jurisdictions are barriers to collaboration.
- Funding is insufficient to address issues within the watershed.

Study Products: Two major products from this study are described below and include a Watershed Strategy and Floodplain Management Strategy. This document is the Watershed Strategy which addresses the overall watershed analysis. The Floodplain Management Strategy has been produced in a separate but associated document; an electronic version is included on the enclosed Compact Disc.

Floodplain Management Strategy: This report includes evaluation of lessons learned from 2005 flooding, identification of hazards, organization of existing policies and constraints, and recommendation of floodplain management measures and tools. It recommends <u>fourteen mitigation actions for implementation</u> with the following highest priority:

- Establish a Watershed Steering Committee.
- Conduct Post-Fire Hydrologic Assessments.
- Develop and Conduct Public Information/Outreach.
- Implement a Flood Warning System (Flood Response Plan/Flood Detection Network).

Watershed Strategy: This document describes watershed issues as defined with stakeholders, includes a review of existing studies and projects, describes planning objectives and actions to address them. Implementation of the actions to address the watershed issues may be carried out by any of the multiple jurisdictions, private or non government organizations. It is intended that this strategy be the basis for prioritizing and bringing resources together to seek solutions. The strategy defined in this document may be the basis for a watershed plan that implements the recommended actions.

Study Results: In addition to the two products described above there have been other outcomes from this study. One of those is increased and improved communication across jurisdictional boundaries and among agencies. The first study kick off meeting in August 2006 is reported to be the first meeting of stakeholders from throughout the entire watershed. Although political boundaries and agency missions remain barriers to collaboration, progress has been made in overcoming them.

The authorized duration of this watershed analysis was two years and it will be finalized in August 2008. Stakeholders agree that continued communication and collaboration across the watershed is necessary and beneficial. The first of ongoing and regular watershed meetings is scheduled for September 19, 2008.

1.0 WATERSHED DESCRIPTION

The Virgin River's headwaters are in Washington, Kane, and Iron Counties of Utah. The lower watershed includes portions of Mohave County, Arizona and Clark and Lincoln Counties, Nevada. The river eventually empties into the Colorado River at Lake Mead in southeastern Nevada. Major tributaries include: East Fork Virgin River, North Fork Virgin River, North Creek, La Verkin Creek, Ash Creek, Santa Clara River, Fort Pearce Wash and Beaver Dam Wash.

Forty eight percent (48%) of the watershed is in Utah, thirty four percent (34%) in Arizona and eighteen percent (18%) in Nevada. The entire watershed covers approximately 5,900 square miles. Figure 1, displays the watershed vicinity in Southwest Utah, Northwest Arizona, and Southeastern Nevada. The study area is defined by three 8 digit hydrologic units (HUC) including the Upper Virgin River (15010008), Lower Virgin River (15010010), and Fort Pearce Wash (15010009).

Figure 1 Watershed Vicinity

1.1 Land Ownership

Figure 2 displays land ownership of the watershed; most of which is under public management. This includes lands managed by the Bureau of Land Management (BLM), National Park Service (NPS), U.S. Forest Service (USFS) and Bureau of Reclamation (BOR). Table 1 below displays land ownership and acres. While the majority of lands in the Arizona and Nevada portions of the watershed are BLM managed, Dixie National Forest includes the northern-most portion of Washington County, UT and Zion National Park is near the headwaters of the Virgin River in eastern Washington County.

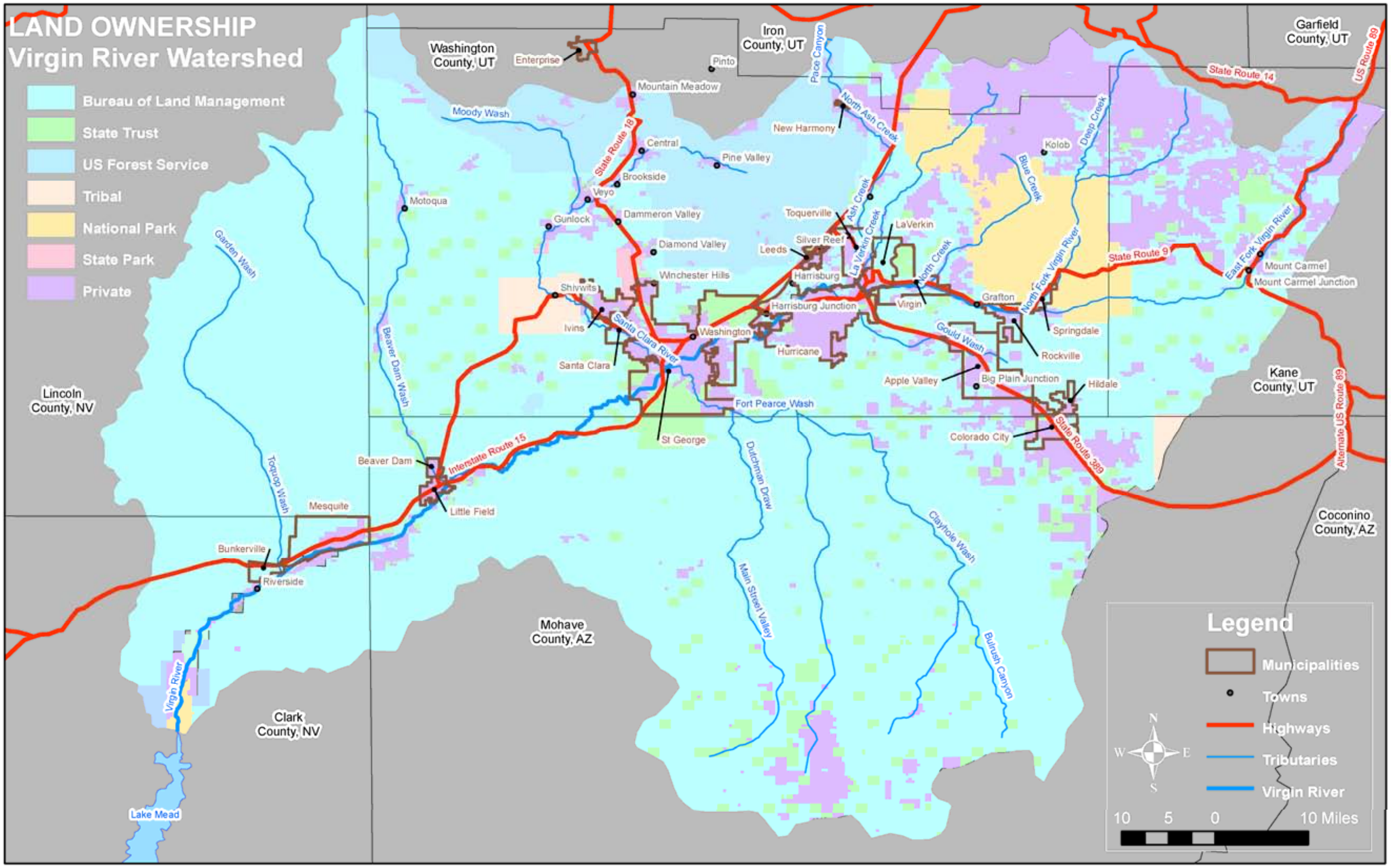

Figure 2 Land Ownership in the Virgin River Watershed

The BLM manages sixty seven percent (67%) of the lands in the watershed, followed by USFS, State Trust, and National Parks, respectively. Although only fourteen percent (14%) of the lands within the watershed are privately owned as depicted by the purple in Figure 2, these lands are under increasing development pressure.

Table 1 Land Ownership within the Watershed

Ownership	Acres	%
Bureau of Land Management	2,565,721	67%
Private	535,002	14%
US Forest Service	295,112	8%
State Trust land	217,867	6%
National Parks/Monuments	149,329	4%
Tribal	33,697	1%
Bureau of Reclamation	13,856	0.4%
State Park/Recreation Area	7,535	0.2%
State Wildlife Reserves	578	0.02%
Total	3,818,697	

1.2 Population

The Virgin River basin is one of the largest free-flowing river basin watersheds in the Western United States. Although there are dams within the watershed, there are none on the Virgin River main stem. It is currently being impacted by a significant level of development and population growth. Much of this development is occurring in lowland areas adjacent to floodplains and high flood hazard areas, which are also critically important habitats for protected and sensitive wildlife species. From 2000 to 2007, Nevada, Arizona and Utah had the top three population growth rates in the nation[1].

Current population in the watershed is approximately 200,000 and is projected to grow significantly in the future. The population of Washington County, UT was estimated at 90,000 in the 2000 Census and is projected to be 415,000 by 2030 and 860,000 by 2060. Kane County with a population of approximately 6,200 is expected to be nearly 10,000 by 2030 and 17,000 by 2060[2]. In the lower watershed

1 www.brookings.edu/metro/intermountain_west.aspx
2 http://governor.utah.gov/dea/projections/2008SubcountyProjections.xls

the estimated current population of 17,000 could grow to 60,000 by 2021[3].

1.3 Landscape

The watershed spans a diverse range of elevations and land cover from over 10,000 ft. in the high mountains in Southwest Utah to the Mohave Desert at nearly 1,200 ft. Higher elevations receive from 25 to 35 inches of precipitation annually and support conifer and aspen Forests. Middle elevations support both mountain shrub lands and Pinion/Juniper forests. Lower elevations within the watershed are semi-arid to arid-desert rangelands and receive as little as 4 inches of precipitation annually.

Figure 3 Vicinity of Pine Valley, UT

Figure 3, is a photo of forested mountains and grass pastures in the vicinity of Pine Valley, Utah. Figure 4, taken near Beaver Dam, Arizona depicts the Mohave Desert ecosystem with Joshua tree forest and creosote shrub lands.

Figure 4 Vicinity of Beaver Dam, AZ

[3] Virgin Valley Water District Presentation, Legislative Committee on Use, Management, snd Allocation of Water Resources. February 15, 2006. Caliente, NV.

1.4 Ecosystem

This arid watershed spans the intersection of three physiographic regions including the Colorado Plateau, the Great Basin, and the Mojave Desert. The Virgin River crosses nearly 150 miles uninterrupted from the mountains above Zion National Park to Lake Mead. It is the only intact river in the Mojave Desert in Nevada. The riparian vegetation includes, but is not limited to, coyote and Goodings willow, arroweed, cottonwood, tamarisk, cattail, quailbush, wolfberry, mesquite and various sedges and grasses. The invasive tamarisk or salt cedar is a threat to the system, its water resources, and species that rely on the system.

The Virgin River is one of the largest riparian corridors in the desert southwest. It is home to more than 200 species of wildlife, which utilize the corridor as a residence or seasonal migration route. It provides important habitat for several federally endangered species including the woundfin, Virgin River chub, southwestern willow flycatcher and Yuma clapper rail. The watershed also supports several important state protected sensitive aquatic species including the flannelmouth sucker and Virgin spinedace. With its relatively good remaining habitat and service as a migration corridor, the Virgin River in Nevada is designated as an Important Bird Area by Audubon.

1.5 Flooding

The Virgin River and tributaries have a long history of flooding resulting from large general storms, snowmelt, or summer thunderstorms. Flooding has been recorded throughout the 1800's and between 1900 and 1971 references are made to twenty seven (27) floods. These various flood events damaged bridges, irrigation canals, dams, homes, cropland, and included the loss of life.

The first recorded damages occurred between December 1861 and February 1862 when rain fell for forty days, and settlements along the Santa Clara River were destroyed. More recently, in 2005 following several weeks of high precipitation, melting snowpack, and large rainstorms, damages were incurred throughout the watershed totaling nearly $200 million. Flash flooding damaged homes and infrastructure in Washington County during the summer of 2007. Flooding and flood risks within the watershed are all described in more detail later in the report.

2.0 WATERSHED ISSUES

This section describes issues within the watershed as they were defined in meetings with stakeholders. The focus is upon those large scale issues that to some extent affect the watershed as a whole. Reports and ongoing activities throughout the watershed are reviewed and summarized in this section with a description of problems and opportunities that could be addressed in the future.

Since watersheds cross jurisdictional boundaries, applying a *watershed perspective*[4] requires a scope which crosses multiple jurisdictions. This analysis applies a watershed perspective to analyzing the Virgin River watershed, while recognizing that jurisdictional and political boundaries exist.

> *"Watershed perspective is the viewpoint which requires that all activities be accomplished within the context of an understanding and appreciation of the impacts of those activities on other resources in the watershed."*

Although there are related efforts ongoing throughout the watershed, most are usually restricted within state or other jurisdictional borders and do not generally apply a watershed perspective. Likewise, there are issues within the watershed that are beyond the scope of a single study or jurisdiction to adequately address.

2.1 Defining Issues

Many of the watershed issues have been reviewed and described in numerous reports. Stakeholders were asked to help focus and prioritize watershed issues during the study kickoff meeting in St. George, Utah in August, 2006. Approximately seventy people participated in that meeting which included presentations and discussion of issues.

A planning exercise was conducted during that kickoff meeting to facilitate discussion and focus the analysis. The Large Group Response Exercise is a step-by-step method to quickly elicit, display, and summarize responses of a large group of people to a set of questions.

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4 USACE Policy Guidance Letter #61- Application of Watershed Perspective to Corps of Engineers Civil Works Programs and Activities.

In addressing each question, individual answers were brainstormed, followed by identification of the most important responses to each, and finally a summary was developed by the group. These are not intended for statistical purposes, but to give an estimation of the ranking of the problems by participants on that day. Fifty-four sheets were collected, although more participated.

2.1.1 Large Group Response Exercise

The following summarizes the responses from the large group response exercise. This included 3 questions asked of the audience, prioritization of answers, and a group summary and discussion of responses. The first question was general and intended to focus upon what the participants believe to be the most significant problems facing the watershed. The second two questions focused upon identifying successful watershed management and what could be done in the future to improve watershed management.

The first question was "*What are the biggest problems facing the watershed*?". Brainstorming sheets were collected after the session and responses counted to give an estimate of the number of responses for any one issue area. These responses are presented in Table 2.

Table 2 Significant issues facing the watershed.

Issue	Responses
Floodplain management, development, flooding and erosion	31
Invasive species (tamarisk, cheat grass)	29
Development pressure, general land use planning, and sustainability	27
Endangered species habitat	15
Water supply, quality, drought	14
Wildfire and its effects	12
Communication/cooperation (or lack of)	7
Channel maintenance (ability to carry out)	7
Water quality, salinity, storm water runoff	6

Additional comments included: water rights abuse, protection of the environment, public use and recreation needs, understanding of groundwater interactions, agriculture, livestock management, conservation ethic, archaeological site protection, and off road vehicle use.

Participants were asked to list those responses that were the most important to them. Most important responses closely match the significant issues listed in Table 2, and confirm the most significant issues people believe to be facing the watershed.

The top five issues in order of number of times participants listed them as the most important are: **Floodplain Management, Land Use Planning, Invasive Species, Water Availability, and River Function (includes habitat, endangered species, channel maintenance)**. Land use planning and invasives were tied for number of times marked most important.

Summary of answers to the second two questions are included here.

Question 2: *How do you recognize successful watershed management*?

- Cooperation-lack of conflict
- Floodplain management/mitigation
- Healthy functioning ecosystem
- Effective planning tools (monitoring)
- Knowing/understanding resources

Question 3: *During the next 10 years what could be done to improve watershed management in the Virgin River Watershed?*

- Develop watershed wide plan
- Manage invasive species/vegetation/habitat
- Manage urban encroachment
- Educate public, provide outreach, and involve locals
- Control and maintain sediment deposits
- Locally control/manage streams and tributaries
- Continue hydrologic monitoring program
- Control off-road vehicles

The issues identified are recognized to be interrelated, and somewhat inseparable. A watershed perspective entails dealing with these interrelated issues rather than addressing every issue as an individual effort. The most significant issues include floodplain management, land use planning, invasive species and river function.

2.2 Current Watershed Activities

Developing this Watershed Strategy included a review of past reports, existing conditions, and ongoing activities. Although there are numerous reports, plans, and actions taking place throughout the watershed, there continue to be outstanding issues. The following section summarizes the existing programs and reports pertinent to the issues defined above.

2.2.1 Programs and Initiatives

There are several ongoing efforts in parts of the watershed and although largely defined by state boundaries, they address multi-jurisdictional issues. Currently, there is no comprehensive effort working to address issues throughout the entire watershed. Existing initiatives are described briefly below with links to additional online information provided, where possible.

Virgin River Watershed Advisory Committee - The Virgin River Watershed Advisory Committee (VRWAC) includes numerous stakeholder groups throughout the Utah portion of the watershed who worked together to develop the Virgin River Watershed Management Plan. The major contributors to that plan include: Washington County Water Conservancy District, Dixie National Forest, Utah Division of Environmental Quality, Bureau of Land Management, City of St. George, and Town of Springdale. Numerous other government and non-governmental entities also participate in the VRWAC.

Virgin River Resource Management and Recovery Program - The Virgin River Resource Management and Recovery Program (Virgin River Program) is a collaborative effort between local, state, and federal partners in the Utah portion of the watershed. Goals are to protect, enhance, conserve, and recover native species in the Virgin River Basin while ensuring that water development can continue in a sustainable manner. The scope of the Virgin River Program mainly includes species recovery but also participation in water management, floodplain protection, restoration, and community outreach. Program partners include: State of Utah Department of Natural Resources, Washington County Water Conservancy District, U.S. Fish and Wildlife Service, U.S. National Park Service, U.S. Bureau of Land Management, Dixie Conservation District, Washington County Farm Bureau and The Nature Conservancy. More information can be found online at http://www.virginriverprogram.org.

Virgin River Conservation Partnership - The Virgin River Conservation Partnership is a collaboration of governments, agencies, and organizations within the lower watershed in Nevada and Arizona. Those entities are working together to develop a comprehensive conservation and management strategy for the Virgin River ecosystem. The Partnership seeks to balance the conservation and restoration of the Virgin River ecosystem with economic development, while promoting ecological sustainability, economic viability, responsible use and stewardship, and long term community benefits.

Virgin River Habitat Conservation and Recovery Plan – Development of the Virgin River Habitat Conservation and Recovery Plan (VRHCRP) was initiated in June 2004 and is anticipated to be completed by the end of 2008. The U.S. Fish and Wildlife Service together with the Bureau of Land Management, City of Mesquite, Clark County, National Park Service, Nevada Department of Wildlife, Southern Nevada Water Authority, and Virgin Valley Water District propose to develop the VRHCRP. The intent of the VRHCRP is to provide a recovery strategy for five species in the Lower Virgin River Basin: Virgin River chub, woundfin, southwestern willow flycatcher, Yuma clapper rail, and yellow-billed cuckoo.

The VRHCRP addresses all lands within the 100-year floodplain of the Virgin River and its tributaries (including ephemeral washes) from the Mesquite Diversion (located approximately 2 miles upstream of the Nevada/Arizona border) to the confluence of Lake Mead, as defined by a line from the southern end of Lower Mormon Mesa, through Fish Island, to Little Bitter Wash. In addition, some recovery actions may be expanded to include all land within the 100-year floodplain of the Virgin River and its tributaries from the Mesquite Diversion upstream to the base of the Virgin River Gorge in Arizona or to the location of the future non-native fish barrier to be established by the Virgin River Resource Management and Recovery Program (Utah program).[5]

2.3 Reports

Activities throughout the watershed have resulted in development of numerous reports and plans. The table in Appendix A summarizes over 60 reports pertaining to the issues identified within the watershed. It includes five categories; floodplain management,

[5] Federal Register: September 27, 2007 (Volume 72, Number 187), http://www.epa.gov/EPA-IMPACT/2007/September/Day-27/i4781.htm

invasive species, land use planning, water availability, and watershed planning. In addition to title, author and date, a brief synopsis of the report is provided. Report availability is cited either by agency or website location where they may be accessed.

Although this synopsis is not comprehensive, it captures the most relevant reports pertaining to activities within the watershed and provides links where additional information may be found. As can be seen there is a substantial amount of ongoing planning and project implementation. This listing provides a picture of the existing conditions and activities within the watershed, but also shows areas where there are gaps.

2.3.1 Floodplain Management

Floodplain regulations are in place and local projects are being implemented to reduce flood risk in various locations throughout the watershed. Appendix A includes approximately twenty five (25) reports pertaining to floodplain management. While much effort is underway in some portions of the watershed, there are numerous challenges and opportunities, including areas previously addressed.

In early January 2005, after several weeks of high precipitation, melting snowpack, and large rainstorms caused significant and widespread flooding. In a watershed context, the flooding was significant because of the regional nature of the event; the amount of damage sustained, and the varied nature of the flood hazards. While the upper watershed sustained relatively little damage due to inundation and experienced peak discharges associated with a relatively low recurrence interval, the lower watershed experienced greater inundation damage and discharges associated with larger return interval events. In spite of these regional differences in behavior, debris accumulation and avulsion were experienced throughout the watershed.

Flooding resulted in severe damages to residences, public roads, bridges, water and sewer systems, caused area wide erosion, and led to the isolation and evacuation of residents from several communities. Estimated flood damages across the watershed were nearly $200 million. Damages to homes and infrastructure included Washington County, Utah, Beaver Dam and Littlefield, Arizona, and Mesquite, Nevada.

2.3.1.1 Floodplain Management Strategy

The overall watershed analysis included preparation of a separate but related report, *Virgin River and Tributaries Floodplain Management Strategy*, pertaining to flood risk management. That effort includes evaluation of lessons learned from 2005 flooding, identification of hazards, existing policies and constraints, and recommends floodplain management measures and tools to be applied within the watershed. An electronic version of the entire report can be found on the attached CD as Appendix B.

Stakeholders listed needs and opportunities for improved floodplain management, which are summarized in Table 3, below. More detailed description of the issues below is provided in the *Floodplain Management Strategy* document itself. Four topics are discussed in greater detail here: communication, post-wildfire hazards, flood warning and response, and additional analyses recommended.

Table 3 Floodplain Management Needs and Opportunities

Technical Floodplain Delineations Erosion Hazard Zone Delineations Design Standards/Guidelines	**Environmental** Watershed/Habitat Management Fire Management Invasive Species Control Environmental Compliance-Regional
Regulatory Floodplain Regulations Drainage/Erosion Hazard Ordinances Permitting/Regulatory Streamlined Land Use Planning	**Education** GIS Database Public Education Materials Community Outreach Presentations
Communication Contacts Database GIS Database Communication Protocols/Tools Flood Response Plans	

2.3.1.1.1 Communication

A common theme heard from stakeholders is the need for improved communication. This includes communication between and within jurisdictions, with landowners, and the public in both emergency and non emergency situations. Communication during the 2005 flood is said to have been adequate although broader communication (interstate and intercommunity) was not as effective.

Jurisdictional boundaries often complicate communication, and this watershed is no exception. For example jurisdictions within the watershed include three (3) states, portions of six (6) counties, two (2) FEMA Regions, (2) Corps of Engineers Districts, (3) USFWS Regions, (3) NRCS State Offices, six (6) BLM Field Offices, not to mention numerous other jurisdictions. Consistent and regular coordination and communication across those boundaries is an ongoing challenge. This is an impediment to both emergency response and planning.

An important part of communication is that of public education. There are sources of information pertaining to flooding available through FEMA, State agencies, and local jurisdictions. Although these materials are available, additional efforts to inform the public and decision makers are recommended.

2.3.1.1.2 Post-Wildfire Hazards

The reference to wildfire under the heading Floodplain Management may seem out of place. However, wildfire and other factors are all interrelated in a watershed and can increase runoff and erosion, affecting floodplain management. The occurrence and severity of wildfires is increasing and is going to likely remain a watershed issue in many locations for years to come. As discussed in the US Geological Survey fact sheet *Wildfire Hazards – A National Threat*, the secondary effects of fire are often more disastrous than the fire itself[6].

> "the secondary effects of wildfires, including erosion, landslides, introduction of invasive species, and changes in water quality, are often more disastrous than the fire itself." USGS, 2006

[6] USGS, 2006. Wildfire Hazards – A National Threat, http://pubs.usgs.gov/fs/2006/3015/2006-3015.pdf

Although not always easily quantified, wildfire effects are well documented. *Wildfire Effects on Watershed Hydrologic Processes: an Introduction for Hydraulic Engineers, Watershed Managers and Planners*[7], summarizes issues and describes effects of wildfire on watershed hydrology. We have included an electronic copy of this report on the accompanying CD as Appendix D. Of importance to floodplain management are:

- Higher peak flows and potential risk for flooding due to decrease in infiltration capacity and increase in surface runoff.

- Debris flow due to surface runoff, higher peak flows and increased sediment yield due to erosion and landslides.

- Increase in soil erosion due to loss of groundcover, soil deterioration, and surface runoff.

- Decrease in slope stability and increasing probability of landslide.

Wildfire Extent - Figure 5 is a map of recent wildfires throughout the watershed, and includes fires that occurred between 1994 and 2006, with a scale from green (oldest) to red (most recent). Red on the map outlines the most recent fires during 2005-06. During the summer of 2005 the lightning-caused West Side Complex and Southern Nevada Complex fires burned hundreds of thousands of acres. Approximately 66,000 acres of Washington County, Utah burned as part of the West Side Complex. The larger Southern Nevada Complex fire burned nearly 740,000 acres, of which, over 200,000 acres are within the Virgin River Watershed. This includes nearly 45% of the Beaver Dam Wash sub-watershed.

***Evaluating Wildfire Effects* –** The effect of these wildfires on watershed hydrology has not been quantified, although qualitatively there is a potential impact to runoff and erosion potential. Under existing authorities and funding Federal land management agencies complete Burned Area Emergency Response (BAER) and Emergency Stabilization and Rehabilitation (ESR) plans to the extent possible.

An ESR plan completed for the West Side Complex fire recommended seeding, deferring of livestock grazing for two years, and monitoring.

[7] Berli, M., Chen, L. and Young, M.H., 2008. Wildfire Effects on Watershed Hydrologic Processes: An Introduction for Hydraulic Engineers, Watershed Managers and Planners. Desert Research Institute, Las Vegas. 42 p.

Without treatment there was considered to be a high risk of soil loss, weed invasion, and medium risk of sediment damage and excessive erosion. The BAER plan for the Southern Nevada Complex recommended treatments for stabilization and recovery as well as additional analyses of runoff and sediment delivery potential for Meadow Valley Wash and Beaver Dam Wash. That Post Fire Hazard Assessment[8] found that due to the lack of post fire hydrological

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8 Post-Fire Flood Hazard Assessment Meadow Valley Wash and Beaver Dam Wash. Ely Field Office BLM. Sept 2007.

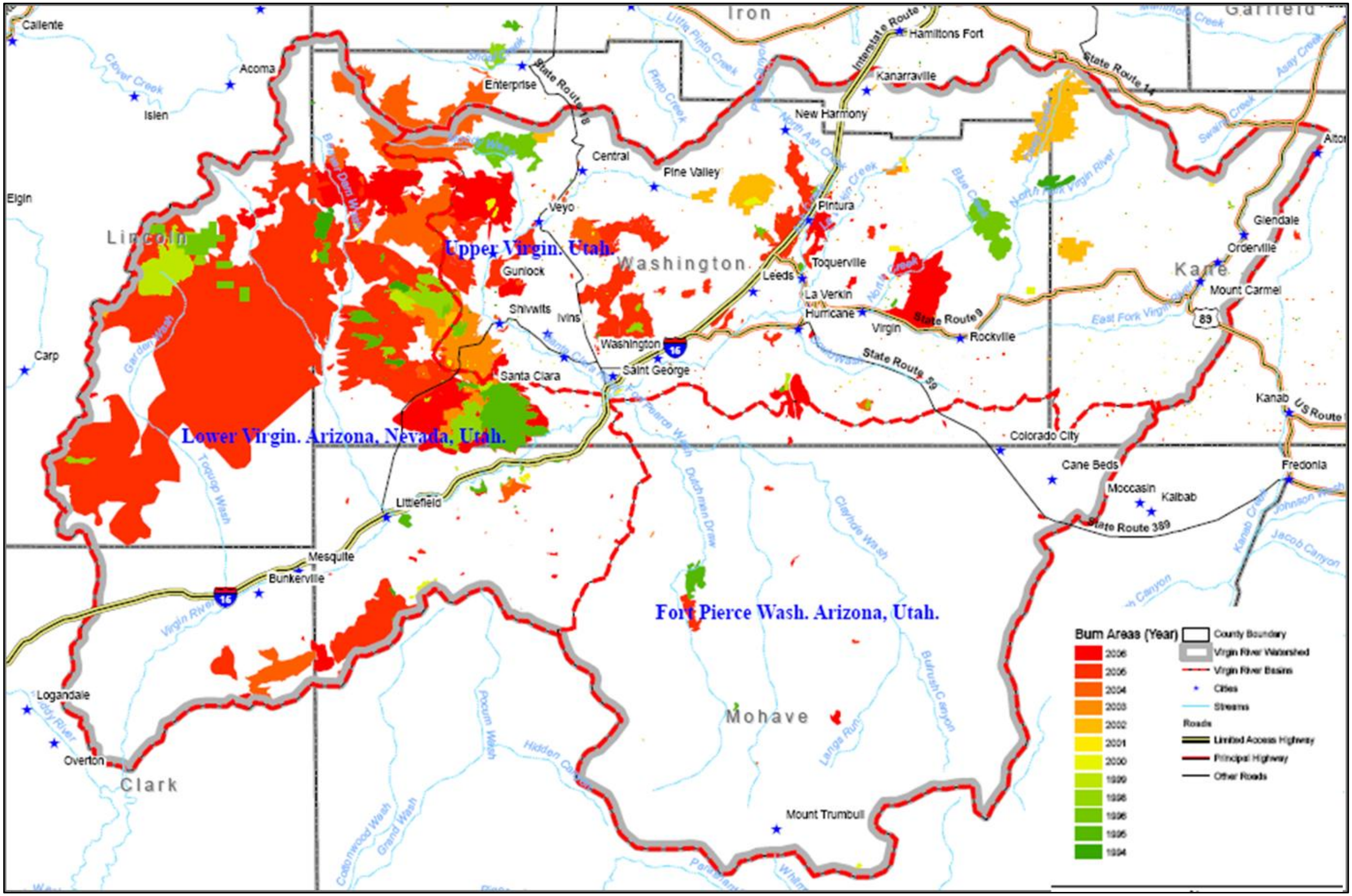

Figure 5 Recent Wildfires in the Watershed (1994-2006 data)

information in the desert environment it wasn't possible to accurately quantify impacts.

In the fall of 2007, Mohave County Flood Control District was in the process of updating a flood risk assessment for the vicinity of Beaver Dam, Arizona. They incorporated the wildfire extent data into their analysis to address the potential increased risk of increased runoff. With nearly 45% of the drainage burned, the updated impacts included a reduced flood warning time for Beaver Dam, AZ from 6 to 3 hours. The County has updated a flood response plan and installed additional flood warning gages into Beaver Dam Wash watershed.

Flash Floods – Flash flooding is often associated with intense summer thunderstorms and rapid runoff conditions in semi-arid environments. In August 2007, flash floods destroyed or damaged homes, roads, and infrastructure along North Creek and the Virgin River near Virgin, Utah and along the Santa Clara River near Gunlock, Utah. One of the damaged homes in the vicinity of Virgin, Utah is shown in Figure 6 below. Burned watersheds may have contributed to increased runoff, erosion and debris.

Figure 6 Flood damage, Vicinity of Virgin, UT (NPS Photo)

2.3.1.1.3 Flood Warning/Response

Although there are numerous stream and precipitation gages throughout the watershed, including some flood warning gages, the data and plans required to provide timely local flood warning are lacking. In some areas, warning is often through neighbor-to-neighbor contact and via telephone. Numerous data gaps exist, especially within drainages that cross State boundaries such as Beaver Dam Wash and Fort Pearce Wash. Figure 7 depicts the various gages present throughout the watershed and clearly shows where there are data gaps. Note also that these are not all flood warning gages.

Existing Gages – Two county flood control districts within the watershed operate Automated Local Evaluation in Real Time (ALERT) gages. Those include Clark Country Regional Flood Control District, NV and Mohave County Flood Control District, AZ. Mohave County is in the process of expanding the system to provide additional coverage to Beaver Dam Wash. The USGS maintains streamgages throughout the watershed and data is available online in near real time. The US Department of Agriculture (USDA) Natural Resources and Conservation Service (NRCS) National Weather and Climate Center operates and maintains an extensive, automated system to collect snowpack and related climatic data in the Western United States called SNOTEL (for SNOwpack TELemetry). Several stations are present in the higher elevations of the watershed.

Data sources and links to online information are included below.

Clark Conty Regional Flood Control District
http://www.ccrfcd.org/ftrs.htm

Mohave County Flood Control District:
http://weather.co.mohave.az.us/perl/DWReports.pl

NRCS, National Weather and Climate Center:
http://www.wcc.nrcs.usda.gov/snotel/Utah/utah.html

USGS Stream gages:
http://www.waterdata.usgs.gov/nwis

National Weather Service:
Flagstaff: http://www.wrh.noaa.gov/fgz
Las Vegas: http://www.wrh.noaa.gov/vef
Salt Lake City: http://www.wrh.noaa.gov/slc

Flood Response Plans - A flood response plan requires assessment of vulnerability, communication plan, and action plans specific to the areas covered. This is combined with forecasting based upon hydrometeorological or upstream stream flow data. Reliable forecasting requires precipitation, land use, and topographic data representative of an area to estimate the runoff-excess.

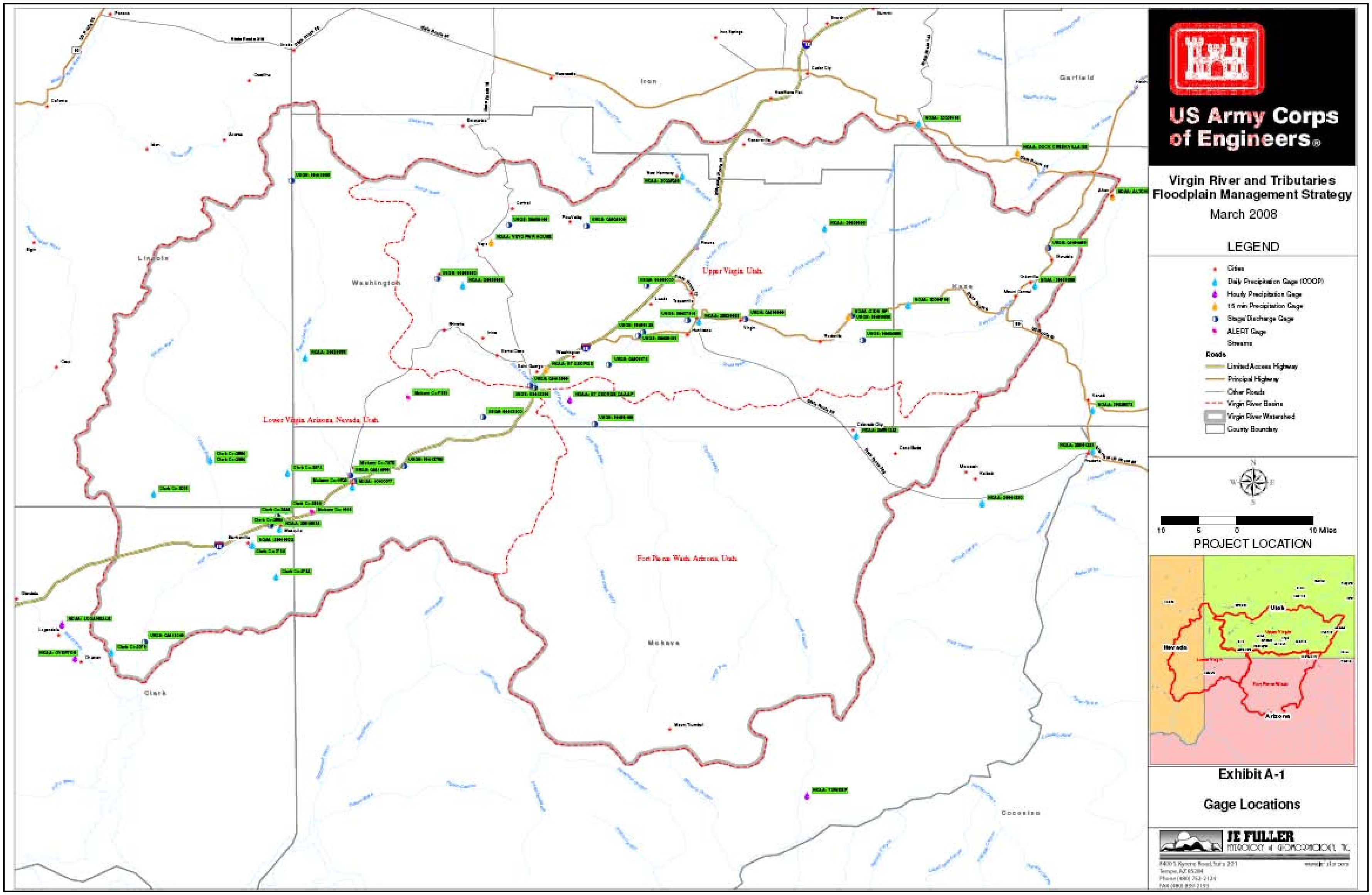

Figure 7 Gage Locations Throughout the Watershed.

2.3.1.2 Additional Analyses Recommended

A substantial amount of floodplain management-related activities have occurred since the 2005 regional flood. However, the risk of flooding is an ongoing issue and changes in the watershed (e.g., development, sedimentation, invasive species, and wildfire) show that there is a need for updated analysis of flood risks and potential damages. Floods of the same or larger magnitude as those that have occurred in the past are likely to occur in the future. Expanding populations contribute to increased flood risk through changes to the watershed and possible development in flood prone areas.

There is a potential risk of flood damages at various locations throughout the watershed that warrant further investigations. Further analyses of potential damages should be conducted in flood prone areas along the Virgin River, Santa Clara River Fort Pearce Wash, Beaver Dam Wash, and possibly smaller tributaries such as North Creek and the East Fork of the Virgin. In addition to the nonstructural measures recommended in the Floodplain Management Strategy, structural measures may be warranted and should be evaluated in several locations.

2.3.2 Invasive Species

Invasive species within the watershed include Salt Cedar (*Tamarix* sp.) or Tamarisk, cheat grass *(Bromus tectorum*) and Red shiner (*Cyprinella lutrensis*). Invasive and non-native species often displace and out-compete native species and even contribute to changed environmental conditions. The problem of invasives extends from aquatic and riparian areas to uplands, and is interrelated with many of the other issues described here. Although numerous efforts to address invasives are underway throughout the watershed, and <u>some</u> collaboration is occurring, there is currently no comprehensive watershed scale coordination or sharing of data. Lack of a comprehensive plan and implementation of individual projects within the confines of political jurisdictions can not be as effective as a coordinated approach.

2.3.2.1 Tamarisk - Tamarisk was introduced to the United States in the late 19th Century for ornamental use as well as erosion stabilization efforts. It originated in Eurasia and has an extensive root system well suited to the arid climates and alkaline soils. The plant can grow to 25 feet tall and often grows in dense thickets. It most commonly propagates by seed dispersal but also vegetatively. Most of the introduced species naturalize only weakly in North America however, four of the five species exhibit weedy life habits under the human-disturbed riparian habitat conditions. The four species (*T. chinensis*; *gallica*; *parviflora*; and *ramosissima*) are difficult to differentiate, either based on geographic distribution or gross morphology. The species within the Virgin River watershed is considered as *Tamarisk ramosissima*.

Degraded conditions of river systems have allowed Tamarisk to exploit most of the Western U.S. where it out-competes native trees and can contribute to numerous problems including; reduced habitat value, lost channel capacity, water loss, increased salinity, and/or fire hazard. Suggested factors contributing to invasion along the Virgin River include land conversion, groundwater drawdown, livestock over-grazing, stream bank stabilization, and over-harvesting of cottonwood, mesquite, and other larger native riparian shrubs and trees for fuel wood and building materials by pioneer settlers and townships.

Although it is an invasive species and contributes to degraded ecological conditions, tamarisk can provide suitable habitat for a number of wildlife species. This includes the endangered southwestern willow flycatcher. A 74-mile section of the Virgin River from Washington Fields Diversion in Washington County, Utah to the upstream boundary of the Overton State Wildlife Area in Clark County, NV was designated Critical Habitat in 2005. The flycatcher nests in dense vegetation along riparian areas of the arid Southwest where it breeds and rears chicks from late spring through summer.

Tamarisk removal efforts are underway by different entities throughout the watershed but the species is difficult to eradicate and continues to dominate many river reaches. The Las Vegas Office of the BLM and National Park Service, Lake Mead has done a significant amount of tamarisk removal in the lower watershed. Approximately 5,000 acres have been treated from the Nevada state line to Lake Mead. The National Park Service has implemented Tamarisk management at both Zion National Park and Lake Mead. Local efforts to address Tamarisk are underway in the vicinity of St. George, Utah through physical removal and introduction of leaf beetles (*Diorhabda elongate*).

The “Tamarisk Toolbox” included in Appendix B describes tamarisk within the watershed including ongoing control efforts and mapping of treatments. Treatment methods and options are summarized in addition to technical and regulatory considerations. Since we were unable to gather all of the pertinent information from jurisdictions across the watershed, there are several data gaps in Appendix B.

2.3.2.2 Cheat grass - Several nonnative grass species are problematic in the Western United States. Cheat grass is a winter or spring annual grass native of Eurasia and the Mediterranean. It is thought to have been introduced to the Intermountain west in the late 1800's, and has now spread throughout much of North America. It invades both disturbed and undisturbed shrub-steppe and intermountain grasslands and has been found at elevations up to 4,000 feet and in areas receiving from 6-22 inches of annual precipitation. The species will out-compete native grasses and even native shrubs and trees. Cheat grass is well adapted to, and even contributes to, frequent fires, giving it a competitive advantage. Natural fire cycles in areas invaded by cheat grass have shortened from 60-100 years to every 3-5 years. Therefore it has the potential to entirely alter an ecosystem.

Species information summarized above can be located online within The Nature Conservancy Element Stewardship Abstract (ESA)[9] and at the USDA Plants Database. The ESA is intended to provide a summary of current information to managers and others that need it for the protection of, or control of important species or communities. The paper provides an excellent overview of cheat grass information including biology, control methods, contacts and literature. The USDA Plants database (http://plants.usda.gov) also includes information on invasive and exotic plants, including cheat grass.

There are numerous control methods currently being investigated including biological, chemical, and manual. Information and references pertaining to them can be located through numerous entities and publications. These include both research and several on the ground activities. So far there is no proven method to control cheat grass and it proves to be a challenge both within the watershed and much of the West.

One such effort is the Mohave Desert Initiative, a collaborative effort among Federal and State agencies to protect and restore native plant habitats in the Nevada, Arizona, and Utah portions of the Mojave Desert ecoregion. Over one million acres in these three states burned

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[9]Element Steward Abstract for Bromus tectorum. The Nature Conservancy http://tncweeds.ucdavis.edu/esadocs/documnts/bromtec.pdf

in wildfires since 2005. These fires have been fueled by invasive, non-native plants such as cheat grass and red brome. Short-term priority actions for FY2008 include a rapid assessment of burned areas and prioritization of areas for protection from wildfire and for restoration; developing standard guidelines for fire suppression in the Mojave Desert and coordinating with personnel from Federal agencies and interagency fire centers on appropriate techniques; continuing ongoing research and monitoring and seeking funds to continue priority projects; developing an outreach strategy and products; and completing proposals for BLM's Healthy Lands Initiative for future on-the-ground projects.

2.3.2.3 Red shiner The red shiner is native to much of central North America, ranging from South Dakota and Wisconsin to Mexico. The fish has been introduced to the Colorado River and Virgin River systems, where it has become extremely abundant. Both of these river systems contain threatened, endangered, and sensitive fish species that are negatively impacted by the red shiner due to competition for food and habitat. The red shiner eats primarily small invertebrates, including zooplankton and insects. It breeds throughout the spring and summer over sand or gravel substrate. Eggs hatch in four to five days. The red shiner is tolerant of poor water conditions, and can often be found in the slow-moving backwaters of rivers and streams. The Red shiner preys upon and competes with native fish.

The Virgin River Program has an ongoing removal effort which includes physical removal and barriers combined with the recovery program for native species. Although red shiner is mentioned as an existing invasive species within the watershed, the Virgin River Program is currently working diligently to address the issue, and additional efforts are not likely necessary. Activities currently underway include construction of fish barriers to prevent upstream movement, and regular eradication activities within the Utah portion of the watershed.

2.3.3 Land Use Planning

Land use planning, development pressure and sustainability were all key issues raised during the St. George kick-off meeting. Issues provided by stakeholders during land use planning discussions include the need for improved communication among agencies, inconsistencies across jurisdictions, lack of watershed wide plans, and a suggested failure to recognize the relationships between uplands and floodplains.

The vast majority (85%) of lands within the watershed are public, managed by either a Federal or state agency. The BLM manages approximately 67% of the watershed. Local and private lands usually fall under the jurisdiction of a county or local land use or zoning ordinance. While floodplain regulations are a component of land use planning, they have been included in the floodplain management category rather than repeated here. This section focuses upon those plans covering and impacting large expanses of the watershed instead of local plans.

2.3.3.1 Federal Land Use Plans - Federal plans include those completed by the BLM, USDA-Forest Service, and National Park Service. These are for the most part programmatic plans with specific projects and activities described and evaluated in project plans and reports.

***BLM* -** With 67% of the watershed is managed by the BLM, plans and actions carried out by BLM s have a significant effect on the watershed as a whole. Five BLM field offices including Ely and Las Vegas, Nevada, the Arizona Strip, and Kanab and St. George, Utah have management authority within the Virgin River Watershed. Resource Master Plans (RMPs) for these management areas, and links to those available online, are listed in Appendix A. Those for Kanab and Ely offices are currently in the process of being updated and include mention of a watershed analysis for land planning purposes.

***Dixie National Forest* -** Approximately 7% of the watershed is within Dixie National Forest, mostly in Washington County and Santa Clara River watershed. The plan most recently updated in 2006 describes a broad strategic direction for land management in the Dixie and Fishlike National Forests. The plan is a guiding document describing standards and guidelines for all resource management activities within the forest. While it provides guidelines, the individual projects or activities are dependent on annual budget and not specifically addressed.

***Zion National Park* -** Last updated in 2001, the plan is intended to provide a general path the National Park Service intends to follow in managing Zion over the next 20 years. The plan will provide a framework for proactive decision making on such issues as visitor use, natural and cultural resource management, and park development, which will allow park managers to effectively address future problems and opportunities.

2.3.3.2 County Plans – These include Mohave and Clark Counties, and a consolidated plan for Southwestern Utah by the Five County Association of Governments in Utah. In addition, a planning process is ongoing for Washington County, Utah through Vision Dixie. These plans are, for the most part, programmatic with specific projects and activities described in more detailed project plans and reports.

Vision Dixie is an initiative in Washington County, Utah which describes a vision for future development in the county. The plan takes a regional approach to describing the vision of future conditions. It has been completed through a public planning process seeking input from the community in a facilitated conversation about growth, gathering their ideas, employing sound data and scenario analysis, and outlining publicly supported principles to guide future land use and transportation decisions.

Watershed Perspective - Large scale programmatic land use plans all take into account other related plans and actions and several discuss collaboration among agencies and across jurisdictions, although application of a watershed perspective is not always apparent. Consideration of the interrelated issues and impacts at a watershed scale may be restricted by jurisdiction.

While the Virgin River Watershed in the scope of this analysis covers approximately 5,900 square miles and is made up of three related fourth level hydrologic units (HUC), a smaller watershed could also be defined for a watershed analysis. For example BLM defines the Fifth level HUC as the basis for watershed evaluations[10]. This includes a mid-level analysis that can evaluate more local problems and activities and is generally no more than 250,000 acres. The interrelated issues and impacts need to be evaluated at an appropriate scale, regardless of jurisdiction.

2.3.4 Water Supply

Water supply, including quality and drought effects was one of the top five issues identified by stakeholders at the St. George kick-off meeting. There are numerous reports and water projects throughout the watershed, too many to summarize. Several water-supply related reports are listed in Appendix A. These are State Water Plans and several watershed scale plans and studies. The need for additional

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[10] BLM Manual 4180-Rangeland Health Standards. 1/19/01

water supply to meet existing and future demand is repeated throughout reports spanning decades. Water quality and issues such as stormwater runoff are more recent additions to the list.

2.3.4.1 State Water Plans –Water plans prepared by each of the states addressing their respective portions of the watershed. For the most part, State Water Plans are limited in scope to include current and projected water demands and water quality issues. While there is mention of other related issues, none are comprehensive in addressing the numerous interrelated issues such as flooding, land use planning, ecosystems, invasive species, etc.

***Utah* -** The Utah State Water Plan includes several volumes, both statewide and by basin. In addition to the most recent State plan, *Utah's Water Resources Planning for the Future* (2001) and several other reports are specific to conjunctive management, drought, and water reuse. This includes a Kanab Creek/Virgin River Basin plan, updated in 2007.

***Nevada* -** The Nevada State Water Plan is designed to help guide the development, management and use of the state's water resources. The plan assesses the quantity and quality of Nevada's water resources, and identifies constraints and opportunities which affect water resource decision making. The plan looks at historical and current water use, and projects demands to the year 2020.

***Arizona* -** The most detailed water plans for the State of Arizona are within Active Management Areas (AMAs); however, rural portions of the state do not yet have detailed plans. The Arizona Water Atlas is being drafted by Arizona Department of Water Resources. The Western Plateau Planning Area section (including the Virgin River Watershed) was released in September 2007. The primary objectives of the Atlas are to: present an overview of water supply and demand conditions, to provide water resource information for planning and resource development purposes, and to help identify the needs of communities throughout Arizona, particularly those outside the AMAs.

2.3.4.2 Water Districts and Projects - Water supply is a challenging concern, and one which affects both the economic and natural health of the watershed[11]. In many cases water districts, established as subdivisions of state government, develop and manage

[11] Virgin River Watershed Management Plan, February 2006.

water projects. Agricultural, municipal, and industrial water in the watershed comes from both surface and groundwater sources.

***Kane County, Utah* –** As a political subdivision of the State of Utah, the Kane County Water Conservancy District serves residents of Kane County. Growth in Kane County over the past 15 years has averaged over 3.0 percent per year. Population is now projected to increase from 6,200 to over 24,000 by the year 2035. It is estimated that population will exceed current water supplies in the future. Projects are being planned to strengthen water development and delivery systems to assist in meeting the future demand. Those are described further in the Lake Powell Pipeline project documents.

***Washington County, Utah* -** The Washington County Water Conservancy District (WCWCD), a political subdivision of the State of Utah, was organized in 1962 under the Water Conservancy Act as a regional water supply agency to develop a water supply for rapidly growing areas in Washington County. The District is primarily a wholesaler of water to other agencies. The main role of the District is to develop or purchase water where it is available for its service area. Population of Washington County is expected to increase from 130,000 present to nearly 650,000 in the next 30-45 years. Currently 72,000 acre feet of water have been developed but the demand in 2038 is projected to be 174,000 acre feet per year. Demands are being met through a combination of conservation and additional water development.

***Lake Powell Pipeline* -** In order to meet the water demands of an ever-growing population in Southern Utah, plans and studies for construction of a pipeline from Lake Powell have been underway for nearly ten (10) years. Studies have indicated that the pipeline is feasible from a construction standpoint. Despite stringent water conservation requirements, current resources may fail to meet the water supply needs by 2012, and planned water resource projects will only extend that supply to meet demand through 2020.

The planned pipeline would originate at Lake Powell, near the Glen Canyon Dam, and would deliver water to Sand Hollow Reservoir, located approximately 10 miles east of St. George. The Pipeline would consist of roughly 139 miles of 69-inch pipe from Lake Powell to Sand Hollow Reservoir and 38 miles of 30-inch pipe from Sand Hollow to Cedar City. The Pipeline would bring 70,000 acre feet of water to Washington County, 10,000 acre feet of water to Kane County and 20,000 acre feet of water to Iron County.

Arizona - Although approximately 2,000 square miles of the watershed are in Arizona, they are sparsely populated. Principle communities include Beaver Dam, Littlefield, and Colorado City. Like everywhere else, these communities are expected to grow in the future with estimated growth in the Beaver Dam/Littlefield area to reach 5,508 by 2050. That is compared to the estimated population in 2000 of 1,532. In 2001-2003 groundwater demand was 2,950 acre-feet per year on average. In 2001-2003 surface water use was approximately 1,650 acre-feet per year on average due to declining agricultural demand. Most basin demand for both surface water and groundwater is for irrigation.

Virgin Valley, Nevada - The Virgin Valley Water District was formed as a political subdivision of Nevada in 1993 to serve residents of the Virgin Valley area of Clark County, Nevada. This includes much of the lower watershed and vicinity of Mesquite and Bunkerville, NV. Water use in the lower watershed is changing from agricultural to residential and municipal as the population grows and land uses change. It is estimated that the population will grow from approximately 18,000 currently to nearly 60,000 by 2021. Water supply in the lower basin comes from a combination of surface and ground water.

Southern Nevada Water Authority (SNWA) - SNWA is a cooperative agency managing water resources in the Las Vegas Valley. SNWA has rights to surface water flows on the Virgin River and can divert from the river up to 190,000 acre-feet of water annually. SNWA's Virgin River water rights are not to exceed a long-term annual average diversion of 113,000 acre-feet per year.

2.3.4.3 Water Quality - Several reports describe water quality impairments and needs within the watershed. Those reports are included with the category of Water Supply in Appendix A and discuss both surface and groundwater quality. The Northeast Clark County Water Quality Management Plan also describes wastewater needs. Total Maximum Daily Load (TMDL) are included for portions of the watershed in Utah and Nevada.

Various segments of the Virgin River are listed on Utah’s Section 303(d) list of impaired waters as described the TMDL water quality study (2004). The parameters responsible for the impairment are total dissolved solids (TDS), dissolved oxygen, temperature, and total phosphorus. The beneficial uses that are listed as impaired include cold water aquatic life, other aquatic life, and agriculture. Several of the listings are due to naturally high concentrations of TDS. Pah tempe (La Verkin) hot springs are a natural contributor of salts and other minerals to the Virgin River and are the significant factor contributing to impairment.

2.3.4.4 Drought and Climate Change – In general terms, drought is the lack of precipitation over a period of time that results in a water shortage. Timing and extent of that shortage may differ in different regions and therefore specific definitions and quantifications vary. Drought is a normal part of climate variations, although it can have significant economic and environmental effects. The Colorado River System has been in a drought since 2000, and this is the worst drought on record for the system. Although there have been some wet years such as 2005, precipitation in the Virgin River basin in Utah has been below the 30 year average for 8 of the past 10 years[12].

The Western Governors Association report *Water Needs and Strategies for a Sustainable Future*[13] summarizes recent findings and projected impacts that could result from climate change. During the Twentieth Century temperatures in the West reportedly rose 2-5 F°. If temperatures continue to rise as has been projected, the impacts to the West could include: smaller snowpack and earlier snowmelt, more extreme flood events, increased evaporation, reduced groundwater supply, more intense and longer lasting droughts, more wildfires, and related water quality impacts.

Water 2025[14], published by the Bureau of Reclamation, defines five realities that are going to shape water supply decisions over the next 25 years. Those include explosive population growth in areas of the West where water is already scarce, water shortages occur frequently in the West, over-allocated watersheds can cause crisis and conflict, Water facilities are aging, and crisis management is not effective in dealing with water conflicts. Water 2025 also identifies regions where there could be potential water supply crisis by 2025, or “Hot Spots”. Those are based on data such as hydrologic conditions, weather

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[12] http://www.water.utah.gov/waterconditions/BasinDroughtReports/VirginKanab/default.asp

[13] Water Needs and Strategies for a Sustainable Future. Western Governors Association. June 2006. http://www.westgov.org/wswc/water%20needs%20and%20strategies-finalrev.pdf

[14] Water 2025. U.S. Bureau of Reclamation. http://www.usbr.gov/water2025/

patterns, endangered species locations, and population growth trends. A portion of the Upper Virgin River is included as a "Hot Spot", and so are the adjacent Lower Colorado River, and Las Vegas Valley.

Although water resource project planning, and implementation are underway and ongoing throughout the watershed, continued drought and impacts of climate change could place additional stresses on system.

2.3.5 Watershed

Seven (7) reports categorized as watershed scale plans are included in Appendix A. These include some of the state water plans described previously. Although they are all large scale plans, not one of these current plans cross State boundaries to address the entire watershed or sub watersheds. Some watershed plans are multipurpose, although most focus mainly upon water supply. Watershed boundaries and waterways cross numerous jurisdictions, although there is not currently a planning document, or ongoing coordination that addresses the interrelated issues within the entire watershed.

2.3.5.1 **Rapid Watershed Assessment -** USDA-Natural Resources Conservation Service (NRCS) has completed a Rapid Watershed Assessment (RWA) for the upper watershed in Utah[15]. An RWA is a set of initial estimates of natural and social resources within a watershed and lists concerns. The information is intended to be used along with other relevant information to assist individuals, communities, non-profits, local, state and federal entities and others to evaluate future conservation activities on a watershed basis.

Rapid Watershed Assessments for the Arizona and Nevada portions of the watershed have been discussed but have not yet been funded. Completion of a tri-state RWA could provide additional information to augment and contribute to addressing the issues identified within this document.

2.3.5.2 Virgin River Watershed Management Plan[16] - The 2006 plan is the most comprehensive of the watershed scale plans within the watershed. It was developed for the portion of the

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[15] NRCS Rapid Watershed Assessment, Upper Virgin (HUC 15010008). http://www.ut.nrcs.usda.gov/programs/RWA/upper_virgin.html

[16] http://wcwcd.state.ut.us/Plan,%20Studies/Watershed%20Mgmt/VRWMP-all.pdf

watershed within Utah and prioritizes problems or needs. It includes the list of recommended project priorities by sub basin, summarized in Table 4 below. These recommendations have similarities to the rest of the watershed. Although some of these recommendations have been implemented, many remain as unmet needs within the upper watershed.

Table 4 Summary of Recommended Projects by VRWMP

Subbasin	**Recommended Projects**
East Fork of the Virgin River	Streambank Stabilization Septic System Education Pinyon and Juniper Tree Removal
North Fork of the Virgin River	Drinking Water Source Protection Education
Upper Virgin River	Proper Land Management Practices Drinking Water Source Protection Education
Ash/La Verkin Creeks	
Lower Virgin River	Establish a County Wide Floodplain Ordinance Tamarisk Removal
Upper Santa Clara River	Septic System Education
Lower Santa Clara River	Development of Off Highway Vehicle Use Plan
Fort Pearce/Beaver Dam Wash	
Virgin River Watershed	Tamarisk Removal Floodplain mapping and establishment of an ordinance Riparian Education (native species, riparian corridor health) Streambank Stabilization Stormwater Management Livestock Management Techniques Removal of unused diversions Eradication of Red Shiner and other Predators Release of water to maintain instream flows Continued investigation of factors limiting native fishes Further investigation of groundwater resources Water Conservation and Reuse

2.4 Summary

This section describes watershed issues as identified by stakeholders and summarizes ongoing efforts and reports. There is a significant amount of information available, including ongoing studies and projects throughout the watershed. However, that information is not always readily available or located, and this document may have missed numerous sources of information. Appendix A provides an overview of the numerous reports located, and provides links to the information available online.

Four common themes were gleaned from the various watershed meetings, observations, and review of reports. Those themes apply to most any issue within the watershed and like the issues themselves are interrelated. They are not unique to this watershed, but could be addressed through implementation of recommendations described in the next section.

1. **Communication and cooperation needs improvement**. Although there is communication across jurisdictions and pertaining to numerous issues, there is room for improvement. This includes both among agencies and the public.

2. **Don't want just another report**. Rather than writing of another report stakeholders have expressed the need for **useful tools and information** to improve watershed management.

3. **Borders and jurisdictions are barriers to collaboration**. Collaboration occurs to a degree, however there is little collaboration occurring among the three states, Federal agencies, and between the Upper and Lower watershed.

4. **Funding is insufficient to address issues within the watershed**. Funding is one of the biggest challenges in addressing watershed issues, especially with complex, multi-jurisdictional issues.

Major watershed issues as identified with stakeholders and confirmed in review of the numerous reports are listed in Table 5. These are not in any priority order and although listed as separate categories, all are to some extent interrelated.

Table 5 Top Five Issues Listed By Stakeholders

Issue	Description
Floodplain Management	Floodplain regulations are in place and studies and projects underway throughout the watershed. However, multiple flood risks remain and management of that risk is an ongoing issue with technical, regulatory, environmental, communication, and education needs identified.
Land Use Planning	Communication among agencies and the public has room for improvement, inconsistencies occur across jurisdictions, lack of watershed wide plans, and lack of recognition of the relationships between uplands and floodplains. Rural communities have expressed a need for useful planning tools and data.
Invasive Species	Invasive species include Tamarisk, cheat grass, Red shiner. Although numerous individual efforts to address tamarisk are underway, and some collaboration is occurring, there is no comprehensive watershed scale coordination or sharing of data.
Water Availability	Water supply and water quality are important aspects of the watershed and needs are described in numerous reports. With growing populations and drought the pressures for the finite water supply will only continue to grow. Water conservation, additional water sources, and evaluation of existing sources are discussed as needs. Groundwater and surface water interaction and salinity have also been expressed as areas of concern within the watershed.
River Function	River function is a balance of sediment and water transport that results in channel morphology and associated biotic communities. It includes unusual events and is dynamic. The issue includes habitat, channel maintenance and endangered species, some of which are currently being addressed.

3.0 WATERSHED PLANNING

Due to the complexities, multi-jurisdictional nature, and scale; funding of watershed projects is one of the most difficult challenges[17]. While it is a challenge to obtain the funding necessary to address all of the issues, there is also an opportunity to utilize a watershed framework and create a strategy that uses the skills and strengths of stakeholders, in coordination with multiple funding sources, to realize implementation of plans, and reach objectives.

Challenges can be met through the development and implementation of a watershed strategy. That is consistent with the Authorization for completing this study with goals of "Established priorities for water resources planning and investment throughout the watershed", and "Collaboration to bring programs and resources together and provide integrated solutions".

Although this watershed effort is fully federally funded, and led by the Corps of Engineers, there is no further Federal obligation for implementation associated with this study. Implementation of the actions to address the watershed issues may be carried out by any of the multiple jurisdictions, private or non government organizations. It is intended that this overall watershed strategy be the basis for prioritizing and bringing resources together to seek solutions.

Actions to address the issues may be carried out by any of the multiple jurisdictions. It is intended that this overall watershed strategy be the basis for prioritizing and bringing resources together to seek solutions.

3.1 Watershed Collaboration

Although there are varying levels of communication and some ongoing collaboration in portions of the watershed there is currently no collaborative watershed partnership. As experienced in other watersheds, such collaboration would be valuable to address the numerous issues.

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[17] http://www.epa.gov/owow/oceans/ndt/documents/9_4Jarocki.pdf

Examples of watershed collaboration and descriptions of lessons learned can be found in numerous reports. One document prepared by the National Policy Consensus Center aims to identify lessons learned from successful watershed collaboration and makes recommendations for state and local officials on ways to enable effective collaboration.[18] That document lists ten (10) reasons to support watershed collaborations, including:

- Provides successful way to address a complex set of issues.
- Allows stakeholders to leverage scarce resources.
- Reduces conflict and litigation.
- Promotes innovation and integration of agency programs.
- Can turn apparently inflexible mandates into opportunities.
- Allow stakeholders to achieve significant, measurable watershed improvements.
- Integrates economic, environmental, and community objectives.
- Provides a means to approach controversial topics.
- Enables direct benefits to agency programs and goals.
- Provides an alternative form of governance for conflicts that don't lend themselves to traditional governmental approaches.

Obviously there are obstacles to collaboration and many ways for it to fail. Many watersheds around the country have established successful collaboration among public and private partnerships. A similar collaboration among stakeholders within the Virgin River Watershed could have the same benefits in addressing the complex issues identified now, and to be realized in the future.

[18] "Watershed Solutions Collaborative Problem Solving for States and Communities. National Policy Consensus Center, 2002. www.policyconsensus.org

3.2 Watershed Planning Objectives

Objectives, in a planning context, are used to help define the scope of a plan. They state a desired outcome, and in doing so help to define what could be accomplished to address an issue or seize an opportunity.

The issues described earlier in this report were used to develop a set of Watershed Objectives. This began in a brainstorming session during a meeting held in Mesquite, NV in May 2007. That initial set of objectives were reviewed, refined, and further developed through discussions with stakeholders in subsequent watershed meetings. Goals, objectives and actions have been organized into six categories that address the following watershed issues:

Watershed Management - This is an overarching issue, within this or any other watershed, and interrelated with each of the other categories. Stakeholders described a need for improved communication and collaboration across jurisdictions and among agencies and the public, as well as funding constraints. Implementing measures to enhance communication and increase collaboration would have significant benefits and enable resources to go further.

Floodplain Management - Although floodplain regulations are in place and projects underway throughout the watershed multiple flood risks remain. Management of flood risk is an ongoing issue, especially with continued development pressure. The *Floodplain Management Strategy* reviews issues and makes recommendations for implementation throughout the watershed.

Land Use Planning - Land use planning by nature is strictly tied to jurisdictions. Through the context of a watershed, large scale land use planning needs to go beyond jurisdictions or at least consider the impacts beyond jurisdictional boundaries. Obviously there are policy and budget constraints in doing so. Several stakeholders stated a need for tools and information that would assist with land use planning decisions, some of which may be available locally, or from agencies.

Invasive Species - Although numerous individual efforts to address tamarisk are underway, and some collaboration is occurring, there is no comprehensive watershed scale coordination or sharing of data. Additional coordination or collaboration on larger scale efforts could be pursued within the watershed.

Water Supply - Water supply and water quality are important aspects described in numerous reports. Projects and studies are underway to address the issues. With growing populations and drought the pressures for the finite water supply will only continue to grow. Several recommended measures are included here but are likely long term.

River Function - River function was defined as "a balance of sediment and water transport that results in channel morphology and associated biotic communities. It includes unusual events and is dynamic". The issue includes some issues that are being addressed by various stakeholders and is also closely tied to other watershed issues.

3.3 Recommendations

Watershed goals pertaining to the six categories above are listed below. Objectives and actions that contribute to meeting those goals and addressing the identified watershed issues are included. Where possible, lead and partner entities that have agreed to or that may be likely to participate in implementation have been included.

The recommendations outlined below are intended to outline a strategic plan which prioritizes the issues and that will bring resources together to seek solutions. Although each of the issues and recommendations are interrelated, those under watershed management seek to address several of the overarching issues within the watershed and should be a priority for implementation.

GOAL 1: Improve Watershed Management, to include communication and collaboration among agencies and the public.

OBJECTIVES	ACTIONS	WHAT
Establish a mechanism for ongoing collaboration throughout the watershed.	Partnership Agreement for a Watershed Steering Committee	Tri state oriented, Not an oversight group, May serve as a funding/organizing mechanism, membership could include technical and administrative levels.
Improve communication between and among stakeholders and agencies.	Hold Regular Watershed wide meetings	Regular forum for sharing of information across the entire watershed, potential work on specific issues.
	Web based tools	Calendar, List Serve, Google Earth

WHO: The Virgin River Conservation Partnership and Washington County Water Conservancy District have agreed to take the lead in organizing ongoing watershed meetings. It is expected that all interested parties throughout the watershed will continue to participate in these meetings.

WHEN: The first meeting has been scheduled for September 19, 2008, in Mesquite, Nevada. Schedule and content of future meetings will be developed by the participants at that time.

BENEFITS: This activity will address several of the overarching problems identified within the watershed. Ongoing meetings provide a regular venue to facilitate improved communication, strengthening of relationships among entities will enable sharing of information and serve to overcome jurisdictional barriers to collaboration. Duplication of effort can be reduced through improved communication and opportunities for collaboration will enable the leveraging of resources to more effectively address watershed issues.

ADDITIONAL INFORMATION: A formalized agreement for ongoing collaboration is recommended in the form of a partnering agreement or Memorandum of Understanding (MOU). Consideration should be given to establishment of a formal watershed coordinator position(s) to facilitate multijurisdictional collaboration across the watershed, which includes 3 separate states.

GOAL 2: Develop a comprehensive approach to floodplain management which will increase public safety and awareness, reduce flood damages, and protect natural and beneficial uses of floodplains.

OBJECTIVES	ACTIONS	WHAT
Fourteen risk mitigation actions are identified in the floodplain strategy. Top four priorities included here.	Steering Committee	Part of watershed meetings, or separate sub groups.
	Post Wildfire evaluations	Improve understanding of effects, consistency of evaluations, and communication of risk
	Flood warning/response	Implement flood warning system
	Public Information	Provide flood risk information to public and decision makers

Steering Committee: It is recommended that a steering committee of stakeholder representatives be convened on a regularly recurring basis for the purpose of maintaining effective communication and implementation of floodplain management activities. This could be at a local level, although communication across the watershed with shared issues is necessary to maintain and improve multi jurisdictional communication.

Post Wildfire Evaluations: For floodplain hazards associated with wildfires, preventative actions are likely to be more effective than emergency actions. This is primarily because flooding from burned areas occurs more rapidly and severely than under non-burned conditions. Following wildfires, several avenues may be pursued to address flooding hazards. They may include risk assessment, awareness, or response. It is recommended that an outline of applicable responses to mitigate flooding in areas impacted by wild fires be a standard part of every Emergency Action Plan (EAP).

A Wildfire Workshop co-organized by USACE and the Desert Research Institute (DRI) was held on June 3rd 2008 at DRI, Las Vegas, under the auspices of the Corps UFDP arid regions demonstration program. The meeting brought together wildfire scientists with land managers and practitioners from various federal agencies (among them USDA-FS, NRCS, BLM, NPS, EPA) to collect and discuss approaches for post-fire peak flow modeling, addressing questions like (a) what models are currently available; (b) what are their strengths and limitations; and (c) can available databases on soil hydraulic properties provide data to run reliable predictions with an empirically/physically based model? A synthesis of the workshop addressing state of the art in wildfire hydrology modeling, current limitations and needs as well as action items will be available by September 2008. A more comprehensive list of hydrology models used to predict wildfire effects on watershed hydrology will be compiled and made available through the USACE-UFDP Wildfire effort in FY08.

For practical applications there is need to identify model(s) which can provide reasonable quantitative predictions of wildfire effects on watershed response with a minimum amount of input parameters. At the Wildfire Workshop, models used by various federal agencies (USDA-FS, USGS, BLM, NPS, EPA) have been identified. These models range from simple but relatively easy and rapid to apply for emergency predictions (empirical, few input parameters; e.g. SCS Curve Number, TR55, USGS-Regression, Rule of Thumb) to complex but with improved predictive power for long-term predictions or design purposes (physically based, many input parameters; (e.g. KINEROS2, HEC-HMS, WEPP). As pointed out at the workshop, there is little known about how well these models actually work and a strong need for model evaluation/validation was identified.

The USACE-UFDP FY 2008 effort on wildfire hydrology will address this issue by evaluating a selection of two to three post-fire hydrology models on a fire affected watershed. A pilot study is underway at Tobin Wash, Washington County, UT, to assess the sensitivity of fire-induced changes in river peak flow to soil- and vegetation-related input parameters (saturated hydraulic conductivity, surface roughness). Tobin Wash is a sub-basin of the Virgin River Watershed and has been affected by a wildfire in 2005 which lead to serious flooding in 2007. KINEROS2 and HEC-HMS were chosen as the two watershed hydrology models to be used for the study. First results of the sensitivity analysis will be presented at the 2008 Annual Conference of the Floodplain Management Association, September 2-5, 2008, San Diego, California.

Flood Warning/Response: Real-time flood data can help reduce injuries, prevent death and decrease property damage. For these reasons it is recommended that communities and agencies operating within the Virgin River watershed establish and maintain a seamless flood detection network. The network should consist of ALERT stations (rain, weather, and stream gage stations) located at strategic locations along the Virgin River and its significant tributaries. Once flood information has been collected, assessed and disseminated, a Flood Response Plan should be executed. It is recommended that the Flood Response Plan be developed as part of the communities' overall Emergency Action Plan (EAP).

An initial evaluation of a flood warning system is being developed under this study. That evaluation will include the following: needs assessment, existing gaging and flood response plans, data gaps, institutional information and constraints. It will describe the scope and estimated costs associated with determining the feasibility of a regional system, instrumentation siting, and flood response planning. This product will be completed by September 2008 and provided to local and state jurisdictions for their use.

Public Information: Floodplain management publications are available through various agencies (see CD). Information within these publications could be filtered, with the most relevant portions being compiled and published in a Floodplain Management Handbook that is applicable for use within the Virgin River watershed. Readily available brochures that educates the general public about flood control, erosion control, and water quality management issues is a cost effective, proactive approach to floodplain management.

WHO: Local jurisdictions, with State and Federal support as applicable.

WHEN: Immediate and Ongoing.

ADDITIONAL INFORMATION: The action listed here are only the top four priorities coming out of the Floodplain Management Strategy. Further detailed information on all fourteen can be found in that document, an electronic version is on the enclosed CD.

GOAL 3: Support and improve Land Use planning efforts throughout the watershed.

OBJECTIVES	ACTIONS	WHAT
Develop planning toolbox for use by local entities.	Model Ordinances, guidelines, data updated and coordinated	Some tools in the Floodplain Strategy. Data and information is also available from various agencies: EPA, FEMA, NRCS, etc
Incorporate non-point source reduction efforts into local land use planning.	Underway, but can be increased and expanded	Means to reduce pollution from diffuse sources, info and resources available from EPA.
Encourage a watershed approach in large scale planning efforts.	*Guideline*	Apply a watershed perspective to land use decisions.

WHO: Local, State and Federal agencies.

WHEN: Ongoing

INFO: The Floodplain Management Strategy includes model ordinances, guidelines and data that can be used by local entities. Various agency programs may also include pertinent information depending on the specific needs.

Although non-point source reduction efforts are underway there may be opportunities to expand them. The U.S. EPA has information available online at http://www.epa.gov/OWOW/nps/.

The Mohave Desert Initiative is one are where a large scale approach to planning may be applicable and provide benefits. In addition the Las Vegas office of the BLM is incorporating applicable action items from this Strategy into their RMP update efforts.

GOAL 4: Manage (monitoring, removal, restoration) Invasive Species to acceptable levels.

OBJECTIVES	ACTIONS	WHAT
Identify priority geographic areas and species.	Establish priorities and develop plan	Watershed based plan mapping and prioritizing treatment needs/options.
Coordinate invasive species activities across the watershed with other activities.	Include in other projects, Comprehensive Weed Management Area	Incorporate invasive species efforts into watershed meetings. Early detection and rapid response should be incorporated into monitoring efforts.
Involve the public in restoration efforts.	Guideline	Project specific.

Watershed Plan: Development of a watershed wide restoration plan would contribute to invasive species management in the watershed.
That plan could include the following components:

- Mapping and Inventory
- Site Specific Treatments
- Cost Estimates
- Environmental Assessment
- Management and Monitoring
- Funding Mechanisms
- Outreach and Education

The Southeast Utah Tamarisk Partnership completed a plan in the summer of 2007, and that plan is an example of what could be implemented in the Virgin River watershed. It and other examples can be downloaded from the Tamarisk Coalition website at www.tamariskcoalition.org.

Coordination: With numerous jurisdictions carrying out activities throughout the watershed there is both a need and opportunity to improve communication among them. This should be a priority topic for watershed meetings.

WHO: Land management and resource agencies currently conducting invasive species work should be involved and could lead this effort. Potential partners include: Bureau of Land Management, National Park Service, US Fish and Wildlife Service, Natural Resource Conservation Service, U.S. Army Corps of Engineers, State agencies, local governments and NGO's such as The Nature Conservancy, Partners in Conservation, or Tamarisk Coalition.

WHEN: Since there are numerous activities underway, the topic of invasive species efforts should be incorporated to the first watershed meeting in September 2008.

BENEFITS: Improved coordination of invasive species related activities would reduce duplication of effort and facilitate the sharing of lessons learned. A watershed wide plan would prove useful in leveraging resources across the watershed, seek additional funding sources, and has more likelihood for a sustainable plan with long term success.

ADDITIONAL INFORMATION: In completing the Appendix C, the Tamarisk Toolbox we have attempted to capture pertinent tamarisk treatment information from throughout the watershed. However, the information located is still incomplete. This further highlights the need for improved communication and coordination of these activities across the watershed.

GOAL 5: Maintain a suitable and sufficient water supply for the watershed.

OBJECTIVES	ACTIONS	WHAT
Evaluate surface/ground water interaction	Modeling and evaluation	Develop basin wide model Evaluate groundwater (wells)
Consider system wide water supply	Modeling and systemic evaluation	Increased storage Conservation strategies Improve efficiency Identify new water sources Water rights within the system
Protect/Improve water quality	Occurring, specific actions could be expanded.	State water quality criteria Drinking water criteria Biological requirements Pollutant sources (point/nonpoint)

WHO: Local agencies with State/Federal support as requested

WHEN: Ongoing

ADDITIONAL INFORMATION: Although water supply and water quality are watershed issues, they are also controversial subjects. Individual jurisdictions are working to address their individual water supply needs at this time. There is not currently a desire to visit water supply issues across the watershed as a whole.

The recommendations to evaluate surface and groundwater through modeling are not likely feasible but are retained here since they were recommended in formulating planning objectives. Information pertaining to potential funding sources to cost share water supply and water quality related projects is provided in the next section.

GOAL 6: Establish, maintain and support a functional river system throughout the watershed.

OBJECTIVES	ACTIONS	WHAT
Identify areas for potential habitat preservation, enhancement and restoration.	Planning and implementation	To some extent this is already within existing management plans. This objective can be related to a watershed plan for invasive species management.
Develop a streamlined permitting process for river maintenance and restoration.		Proponents need to apply for permits, and further discussion on this topic will be necessary with regulatory agencies (State and Federal).
Maintain natural river channel and dynamics where feasible.	Guideline	This is more of a guideline for consideration in development of other plans.
Integrate conservation planning for sensitive species.	Currently occurring	Virgin River Habitat Conservation and Recovery Program, Clark County Multi Species HCP, Virgin River Program.

WHO: Land managers, local, state and Federal agencies, and NGO's.

WHEN: Ongoing.

ADDITIONAL INFORMATION: Much of this is currently occurring under existing programs. Although existing management plans identify potential areas for preservation, enhancement and restoration additional opportunities exist and could be pursued. This should be tied to a watershed plan for invasive species management and is not restricted to aquatic habitat. A healthy and functional river system is also tied to riparian and upland areas within the watershed.

3.4 Watershed Plan

Through this watershed analysis stakeholders have identified priority issues, planning objectives, and potential actions to address those issues. Actions identified are a major step toward watershed planning, but need to be expanded upon with detailed planning and implementation. That implementation plan would identify tasks, lead parties and partners, costs, funding mechanisms, and milestones.

Recommended short (<1yr) and mid term <3 yrs) priorities include the following:

- Hold regular and recurring watershed meetings.
- Develop a formal mechanism for watershed collaboration that includes participation from stakeholders within all 3 states (UT, AZ, NV).
- Implement a floodplain management steering committee to maintain effective communication and implementation of flood risk management.
- Conduct post wildfire hydrologic evaluations to include assessment of flooding and related risks.
- Evaluate feasibility of a implementing a flood warning system, and related flood response plans for the watershed.
- Complete an implementation plan for invasive species management and restoration activities, throughout the watershed.

4.0 WATERSHED FUNDING

Funding for addressing watershed issues can come from any number of sources. However, funding of watershed projects is often more challenging due to complex cost, organization, intergovernmental and time factors[19]. Although there are challenges, utilizing a watershed framework allows stakeholders to share strengths and leverage resources, and reduce duplication of effort.

The following list compiles information pertaining to potential funding partners, and searchable databases of funding information.

U.S. Army Corps of Engineers - The Army Corps of Engineers provides engineering services including water infrastructure, environmental management and restoration, response to natural and manmade disasters, and engineering and technical services to other Federal agencies. Civil works missions include planning, designing, building and operating water resources and other civil works projects. Authorities that may be applicable to assist in addressing watershed issues are listed below.

Individually Authorized Studies and Programs (General Investigations) - The Corps may investigate water resource problems and opportunities in response authorizations from the Congress. Authorizations are contained in public laws and in resolutions of either the House Public Works and Transportation Committee or the Senate Environment and Public Works Committee. The focus of the studies is on determining whether a Federal project, responding to the problems and opportunities of concern, should be recommended. Authorities for studies in the Virgin River Watershed are currently included in Section the Flood Control Act of 1938 and Section 4094 of the Water Resources Development Act of 2007.

Before any project can be constructed, planning studies must be conducted. There are several types of planning studies, but the most

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19 http://www.epa.gov/owow/oceans/ndt/documents/9_4Jarocki.pdf

common studies are those that are conducted in two phases, the Reconnaissance Phase and the Feasibility Phase. The Reconnaissance study phase determines if there is a Federal interest to proceed to a feasibility study and defines the scope and cost of the study, and non federal interest to cost share that study. Feasibility studies are cost shared 50% Federal, and 50% non Federal. The report results in recommendations to Congress for or against Federal participation in solutions to the water resource problems and opportunities identified in the study. A recommendation for Federal participation is generally a recommendation for construction authorization.

Small Flood Damage Reduction Projects - Section 205 of the 1948 Flood Control Act, as amended, provides authority to the Corps of Engineers to plan and construct small flood damage reduction projects that have not already been specifically authorized by Congress. A project is accepted for construction only after detailed investigation clearly shows its engineering feasibility, environmental acceptability, and economic justification. There are two types of projects: structural and nonstructural. Structural projects may include levees, flood walls, diversion channels, pumping plants, and bridge modifications. Nonstructural alternatives, which have little or no effect on water surface elevations, might include such measures as floodproofing, relocation of structures, and flood warning systems. In the feasibility study the problem is defined, the federal interest is determined, potential solutions are identified, and the most feasible plan is chosen.

Costs are shared between the federal government and a non-federal sponsor in accordance with the Water Resources Development Act of 1986, as amended. During construction the local sponsor must contribute a minimum of 35 percent of the total cost of a project, with credit granted toward this amount for providing lands, easements and rights-of way, and pay a minimum cash requirement of 5 percent of the total project cost. The maximum federal expenditure per project is $7 million, which includes both planning and construction costs. Costs of lands, easements, and operation and maintenance must be non-federal.

Emergency Streambank and Shoreline Protection - Section 14 of the 1946 Flood Control Act, as amended, provides authority for the Corps of Engineers to plan and construct emergency streambank and shoreline protection projects to protect endangered highways, highway bridge approaches, public facilities such as water and sewer lines, churches, public and private nonprofit schools and hospitals, and other nonprofit public facilities. The unstable conditions caused by streambank and shoreline erosion call for prompt action to eliminate the threat to public safety and to prevent interruption of vital services. A project may include new streambank or shoreline protection works, or it may repair, restore, or modify existing works. Each project must constitute a complete solution to the problem and not commit the federal government to additional improvements to ensure effective protection. A project is accepted for construction only after investigation shows its engineering feasibility, environmental acceptability, and economic justification.

Federal costs are limited to not more than $1,000,000 in one locality during any fiscal year. Costs of lands, easements, and operation and maintenance of the project must be nonfederal. Costs are shared between the federal government and a non-federal sponsor in accordance with the Water Resources Development Act of 1986, as amended. The first $40,000 of study funds are 100 percent federal. Any remaining study funds and the costs of construction are shared according to the formula in the law. Credit is given for lands, etc., dedicated to the project, but at least 5 percent of the cost must be provided in cash. The local sponsor (a State, local, or tribal government) must have the legal and financial capability to fulfill local cooperation requirements.

Flood Plain Management Services Program (Section 206 of the 1960 Flood Control Act (PL 86-645)) provides the full range of technical services and planning guidance that is needed to support effective flood plain management. Technical services include the development or interpretation of site-specific data on obstructions to flow, flood formation and timing, flood depths or stages, flood water velocities, and the extent, duration and frequency of flooding. On a larger scale, the program provides assistance and guidance in the form of “Special Studies” on all aspects of floodplain management planning. Some of the most common types of Special Studies include:

- Floodplain Delineation/ Flood Hazard Evaluation Studies
- Dam Break Analysis Studies
- Flood Warning/ Preparedness Studies
- Regulatory Floodway Studies
- Comprehensive Floodplain Management Studies
- Flood Damage Reduction Studies
- Urbanization Impact Studies
- Stormwater Management Studies
- Floodproofing Studies

- Inventory of Floodprone Structures
- Preparation of Guides and Pamphlets

Planning Assistance to States Program – The Program, as authorized by Section 22 of the Water Resources Development Act of 1974, as amended. Under this program, the Corps is authorized to use its technical expertise in water and related land resources management to help States, Indian Tribes, and public entities within States with studies of their water resources problems and needs.

Typical studies addressed under the PAS Program are flood control, flood hazard mitigation, flood plain delineation, flood warning systems, water supply, water conservation, water quality, hydropower, erosion, watershed studies, environmental studies, ecosystem studies, recreation and navigation. The program is cost-shared on a 50-50 basis, with a State, an Indian Tribe, a county, a city, or a regional governmental agency serving as a non-Federal sponsor.

U.S. Bureau of Reclamation (Reclamation) - Reclamation has commitments to operate and maintain existing water and power facilities efficiently and reliably, to sustain the health and integrity of ecosystems while addressing growing water needs, and to assist states, tribes, and local entities in resolving contemporary water resource management issues. The most commonly used programs are described below.

Funding for Reclamation's work is provided primarily by Congress in its annual Energy and Water Development Appropriations bill for water and related natural resources management, development, and protection. Cost-sharing by other entities complements Congressional funding for most resource management programs. Cost-sharing entities are not limited as to type, but they are usually municipal and agricultural water suppliers.

Drought Planning and Emergency Assistance - This program provides for activities that minimize economic losses and other damages resulting from drought conditions. The two major components of the program are:
To provide assistance during times of drought. This involves identification of local opportunities and financial assistance for construction of temporary facilities and implementation of water conservation measures to minimize losses and damages resulting from drought events.

To provide assistance for the preparation of drought contingency plans. This may involve providing technical and/or financial assistance and guidance for developing plans to prevent adverse effects from future drought events.

Authorities:
The Reclamation Act of 1902, June 17, 1902, as amended
P.L. 102-250, Reclamation States Emergency Drought Relief Act of 1991, as amended

Native American Affairs Program - This program supports selected Reclamation activities with Indian Tribes, including providing technical assistance to recognized tribes to protect, manage, and develop water and related resources; participating on Federal negotiating teams; providing policy and technical support for implementation of water rights settlements; providing support for the Indian Self-Governance and Self-Determination programs; and administering and coordinating Reclamation's Native American Affairs Program.

Technical assistance activities include development for water supplies on reservations and developing partnerships in water resources and related resource training. Small construction activities in the Lower Colorado Region include exploratory well drilling, irrigation rehabilitation, small reservoir improvements, and rehabilitation of springs and catchments.

Authorities:
The Reclamation Act of 1902, June 17, 1902, as amended
P.L. 93-638, Indian Self-Determination Education and Assistance Act, January 4, 1975, as amended
P.L. 103-413, Indian Self-Governance Act of 1994, October 25, 1994
E.O. 13021, Tribal Colleges and Universities
P.L. 67-85, Snyder Act of 1921, November 2, 1921

Planning Investigations Program - This program involves the identification and evaluation of ways to meet water quantity, water quality, and environmental enhancement needs through management of resources and facilities. This assists state, local, and tribal entities in managing existing water supplies; developing strategies and processes for dealing with water and related natural resource issues; identifying long-range needs and constraints; and identifying water supply and management options available. This program also provides assistance to tribes as needed to develop planning and resource management capabilities.

An important aspect of this program is the creation of partnerships with non-Federal entities to perform studies or other activities to address resource needs. Non-federal cost-sharing is required, with a minimum contribution of 50 percent. Cost-share requirements may be reduced to 10 percent for Tribes, if financial hardship is demonstrated. The cost-share contribution may include in-kind contributions of services for studies or other activities.

The program is flexible in terms of the role that the non-Federal partner plays in performing a study. Reclamation participates in the review and development of planning policies, participation and management overview in special studies requested by other natural resource management agencies, and the review and preparation of study plans and cost-sharing agreements for proposed investigations.

Authorities:
The Reclamation Act of 1902, June 17, 1902, as amended
P.L. 93-638, Indian Self-Determination Education and Assistance Act, January 4, 1975, as amended
P.L. 102-575, Title XVI, Reclamation Wastewater and Groundwater Study and Facilities Act, October 30, 1992, as amended
Other specific authorities may be required depending on the nature of the planning investigation proposed.

Title XVI – Water Reclamation and Reuse Program - Title XVI of Public Law 102-575 as amended by Public Law 104-266 authorizes Reclamation to undertake "a program to investigate and identify opportunities for reclamation and reuse of municipal, industrial, domestic, and agricultural wastewater, and naturally impaired ground and surface water, and to conduct research, including desalting, for the reclamation of wastewater and naturally impaired ground and surface water." Reclamation is authorized to financially participate up to 25 percent or $20 million, whichever is less, in the design and construction of facilities.

Appraisal studies under this program may be fully Federally funded. Appraisal studies identify opportunities for reclamation and reuse and recommend whether a more detailed feasibility study should be undertaken. Feasibility studies are more detailed and generally result in a recommendation to fund a specific project. A minimum cost-sharing match of 50 percent, consisting of either cash or in-kind services, is required.

Reclamation places a priority on funding projects that are economically justified and environmentally acceptable in a watershed context, that are not eligible for funding under another Federal program, and that directly address Reclamation priorities, such as providing instream flows for Federally endangered or threatened species, meeting the needs of Native American communities, and meeting international commitments.

Authorities:
P.L. 102-575, Title XVI, Reclamation Wastewater and Groundwater Study and Facilities Act, October 30, 1992, as amended
P.L. 104-266, Reclamation Recycling and Water Conservation Act of 1996, October 9, 1996

Water 2025 Program - The Challenge Grant Program is the heart of the Water 2025 Program. Collaborative projects are sought with local partners that will stretch existing water supplies by improving water conservation and management. Through this program, Federal funding, awarded on a competitive basis, is provided to irrigation and water districts for up to 50 percent of the cost of projects involving conservation, efficiency, and water marketing. More information can be found at the official Water 2025 – Preventing Crises and Conflict in the West website: http://www.doi.gov/water2025/index.html

Authorities:
Annual appropriations - Public Law No. 108-309, Making Continuing Appropriations for the Fiscal Year 2005, and for Other Purposes

Water Conservation Field Services Program - This program provides for the coordination of water management and conservation efforts with water users (e.g., Colorado River water service contract holders) and other non-Federal entities that have a tie to a Reclamation project. The program provides for water quality monitoring in cooperation with state and local entities, water conservation office support centers and training, improvements in water measurement and accounting, oversight of repayment water service contracts and entitlements, and studies of various methods for water conservation and optimization, including crop water use information and research coordination on interagency water conservation project activities. A 50 percent cost-share is require.

Federal assistance through grants or cooperative agreements may be available as part of the Water Conservation Field Services Program for projects emphasizing one of the following four program components:

Development and preparation of 5-year water conservation plans;
Conservation information and education activities;
Demonstration of innovative conservation technologies; and
Implementation of effective efficiency measures.

Authorities:
P.L. 97-293, Reclamation Reform Act of 1982, October 12, 1982, as amended
P.L. 74-46, Soil and Moisture Conservation Act of 1935, April 27, 1935, as amended

Wetlands Development - This program provides for the development of design criteria, strategies, and implementation of wetland enhancement projects within Reclamation project areas and other Federal land interests that improve water quality, wildlife habitat, and aesthetics. Activities include wetlands demonstration projects designed to improve effluent treatment and reuse to increase wetlands habitat, and dredging and construction of marsh and backwater areas for waterfowl, shorebirds, migratory birds, and endangered fish.

Authorities:
Reclamation Act of 1902, June 17, 1902, as amended
P.L. 101-233, North American Wetlands Conservation Act, December 13, 1989

U.S. Environmental Protection Agency - The U.S. Environmental Protection Agency website includes the *Catalog of Federal Funding Sources for Watershed Protection*. The web site is a searchable database of financial assistance sources (grants, loans, cost-sharing) available to fund a variety of watershed protection projects. To select funding programs for particular requirements, use either of two searches below. One is based on subject matter criteria, and the other is based on words in the title of the funding program. That Catalog can be found at: http://cfpub.epa.gov/fedfund/

EPA also lists various Watershed Funding Programs under its purview at http://www.epa.gov/owow/funding/federal.html. A synopsis of those accessed from the EPA webpage (7/25/08) is below. Specific program information should be obtained from listed points of contact.

Community Action for a Renewed Environment (CARE): CARE is a competitive grant program that offers an innovative way for a community to organize and take action to reduce toxic pollution in its local environment. Through CARE, a community creates a partnership that implements solutions to reduce releases of toxic pollutants and minimize people's exposure to them. By providing financial and technical assistance, EPA helps CARE communities get on the path to a renewed environment.

Clean Water State Revolving Fund: The Clean Water State Revolving Fund programs provided more than $4.5 billion annually in recent years to fund water quality protection projects for wastewater treatment, nonpoint source pollution control, and watershed and estuary management.

Drinking Water State Revolving Fund: The Drinking Water State Revolving Fund makes funds available to drinking water systems to finance infrastructure improvements. The program also emphasizes providing funds to small and disadvantaged communities and to programs that encourage pollution prevention as a tool for ensuring safe drinking water.

Environmental Education Grants Program: This program supports environmental education projects that increase the public awareness about environmental issues and increase people's ability to make informed decisions that impact environmental quality. EPA awards between $2 and $3 million annually. More than 75 percent of these grant recipients receive less than $15,000.

Environmental Justice Grant Programs: These programs provide financial assistance to organizations 1) working on projects to address local environmental and/or public health issues in their communities and 2) building collaborative partnerships to identify local environmental and/or public health issues

Five Star Restoration Program: The Five Star Restoration Program brings together students, conservation corps, other youth groups, citizen groups, corporations, landowners, and government agencies to provide environmental education and training through projects that restore wetlands and streams. The program provides challenge grants, technical support, and opportunities for information exchange to enable community-based restoration projects. Funding levels range from $5,000 to $40,000, with $20,000 as the average amount awarded per project. When the funding is combined with the contributions of partners, projects that make a meaningful contribution to communities become possible.

Nonpoint Source Pollution Funding: This program, which includes Clean Water Act Section 319 grants and Nonpoint Source Minigrants, provides grants to address nonpoint source pollution.

Regional Grant Opportunities: EPA's ten regional offices provide information on both regional and national sources of funding for a variety of water and watershed related projects.

Targeted Watershed Grants (NOTE- No longer accepting applications) The Targeted Watershed Grants Program is designed to encourage successful community-based approaches and management techniques to protect and restore the nation's waters. Any governmental or nonprofit non-governmental entity is eligible to receive a grant under this program, and inter jurisdictional watershed partnerships are encouraged. Through these grants, EPA expects to see real environmental results, such as the return of native fish species and increased recreational opportunities and to discover innovative solutions to improving and sustaining water quality.

Wetlands Funding: Includes information on EPA grant opportunities including Wetlands Program Development Grants, Five Star Restoration Grants, the State Revolving Fund program, and other sources of federal funding for protecting wetlands. Information about Tribal Regulatory Programs and Tribal Watershed Planning is also available.

Additional EPA Funding Opportunities for Water Includes information on other sources of funding for projects that address waste water and drinking water issues and improve water quality (Beach Act Grants, Water Pollution Control Program Grants, and Water Quality Cooperative Agreements). Additionally, specific information for Tribes is available.

Federal Emergency Management Agency (FEMA)

Pre-Disaster Mitigation Grant Program provides funding for hazard mitigation planning and implementation prior to a disaster event. The program has specific restrictions on use of funds including the following ineligible project activities: major flood control projects; warning and alert notification systems; phased or partial projects; studies that do not result in a project; flood studies or mapping;

projects that solely address a manmade hazard; response and communication equipment; projects that solely address maintenance or repairs of existing structures, facilities, or infrastructure; and any project for which another federal agency has primary authority. For more information, visit http://www.fema.gov/government/grant/pdm/index.shtm

Hazard Mitigation Grant Program (HMGP) provides grants to States and local governments to implement long-term hazard mitigation measures after a major disaster declaration. The purpose of the HMGP is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster. The HMGP is authorized under Section 404 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act. For more information, visit http://www.fema.gov/government/grant/hmgp/

Examples of projects include, but are not limited to:

- Acquisition of real property for willing sellers and demolition or relocation of buildings to convert the property to open space use.

- Retrofitting structures and facilities to minimize damages from high winds, earthquake, flood, wildfire, or other natural hazards.

- Elevation of flood prone structures.

- Development and initial implementation of vegetative management programs.

- Minor flood control projects that do not duplicate the flood prevention activities of other Federal agencies.

- Localized flood control projects, such as certain ring levees and floodwall systems, that are designed specifically to protect critical facilities.

- Post-disaster building code related activities that support building code officials during the reconstruction process.

Repetitive Flood Claims Program provides funding to assist states and communities to reduce flood damages to insured properties that have had more than one claim to the NFIP. The primary role of this program is the acquisition of insured properties subjected to repeated flood damage. To be eligible, subject properties must be deed restricted for open space into perpetuity. For more information: http://www.fema.gov/government/grant/rfc/index.shtm

Map Modernization Management Support (MMMS) Program provides grants to assist ongoing flood hazard mapping management efforts by local, regional, and state agencies. Program eligibility is limited to communities participating in and in good standing with the NFIP. Specific requirements of the program are the creation of a data collection and delivery system including a geo-spatial system which supports risk management applications and provides reliable flood hazard data. For more information, visit http://12.46.245.173/pls/portal30/CATALOG.PROGRAM_TEXT_RPT.SHOW?p_arg_names=prog_nbr&p_arg_values=97.070

Flood Mitigation Assistance Program bears a number of similarities to the FEMA Repetitive Flood Claims Program and the FEMA Pre-Disaster Mitigation Grant Program. The program provides funds to purchase or remove NFIP-participating properties from floodplains. Additionally, the program provides funding for planning activities which do not match the following ineligible activity types: flood studies or flood mapping; risk assessments, technical assistance, information dissemination or workshops not resulting in a FEMA-approved Flood Mitigation Plan; ground disturbing activities; and non-flood planning activities. For more information, FEMA has developed a program guidance document which is available at http://www.fema.gov/library/file?type=originalAccessibleFormatFile&file=fy2007_fma_guidance.txt&fileid=136080a0-6f06-11db-8645-000bdba87d5b

U.S. Geological Survey: As the primary Federal science agency for water-resource information, the USGS monitors the quantity and quality of water in the Nation's rivers and aquifers, assesses the sources and fate of contaminants in aquatic systems, develops tools to improve the application of hydrologic information, and ensures that its information and tools are available to all potential users. The Cooperative Program has been a highly successful cost-sharing partnership between the USGS and water-resource agencies at the State, local, and tribal levels. Program information is online at http://water.usgs.gov/coop/

USDA, Natural Resources Conservation Service: The NRCS administers a broad range of programs to assist landowners, communities, and tribal nations with conserving and protecting natural resources. All conservation programs are voluntary and provide such incentives as technical and cost-sharing assistance for the planning and implementation of conservation systems. Some programs provide payments for placing eligible lands into conservation easements. NRCS's conservation programs are designed to help people reduce soil erosion, improve water quality, increase wildlife habitat, and reduce damages caused by floods and other natural disasters. Public benefits include enhanced natural resources that help sustain agricultural productivity and environmental quality while supporting continued economic development, recreation, and scenic beauty. Conservation assistance is provided in partnership with conservation districts, tribal nations, and a host of local, state and federal natural resource agencies. Further information is available from your local USDA Service Center or on the web at http://www.nrcs.usda.gov/programs

Watershed Protection and Flood Prevention Act is implemented through three programs by the NRCS: Watershed Surveys and Planning, Watershed Protection and Flood Prevention Operations, and Watershed Rehabilitation. Traditionally, these programs have been implemented as joint studies between the NRCS and other state, federal, and local agencies. More information is available at http://www.nrcs.usda.gov/programs/watershed/

Conservation Technical Assistance Program provides NRCS technical resources to "reduce soil loss from erosion; …reduce potential damage caused by excess water and sedimentation or drought;…and assist others in facilitating changes in land use as needed for natural resource protection and sustainability." Assistance is available to a variety of entities both public and private. Additional information is available at http://www.nrcs.usda.gov/programs/cta/

Emergency Watershed Protection Program provides post-event rehabilitation and protection assistance. Typical program activities include debris removal from waterways, vegetation restoration, and bank stabilization. Triggering of this program is contingent upon an official federal state of disaster declaration. Additional information at http://www.nrcs.usda.gov/programs/ewp/

Tamarisk Coalition: The Tamarisk Coalition is a non profit organization with a mission to provide education, technical assistance, and coordinating support for the restoration of riparian lands. They have developed an extensive list of possible funding opportunities applicable to invasive species management and restoration. That document is attached in Appendix B, Tamarisk Toolbox but can also be downloaded from the following website: http://www.tamariskcoalition.org/tamariskcoalition/FundingOpportunities.html

Non point Education for Municipal Officials (NEMO): Arizona NEMO is a charter member of the National NEMO Network. NEMO stands for Non-point Education for Municipal Officials. The goal of NEMO is to educate land use decision makers to make choices and take actions that will lessen nonpoint source pollution and protect natural resources. This will be accomplished by non-regulatory, research-based education using geospatial information and other advanced technologies for outreach, education, analysis and research. Arizona NEMO website has a wealth of information and links to funding sources as well. http://www.srnr.arizona.edu/nemo/

Virgin River Watershed Analysis
Appendix A: Summary of Reports

FLOODPLAIN MANAGEMENT RELATED REPORTS			
Report	**Author//Date**	**Description**	**Availability**
Arizona			
DRAFT Hydrologic Analyses: Portions of the Virgin River and Beaver Dam Wash Mohave County, AZ	FEMA Region IX, January 2006	Presents the methodology and results of the hydrologic analyses performed for a portion of the Virgin River and Beaver Dam Wash in the Littlefield Area of Mohave County, Arizona. The results of these hydrologic analyses will be used in the hydraulic analyses to develop flood information for use by FEMA in making determinations regarding potential Hazard Mitigation Grant Program (HMGP) projects.	FEMA, Mohave County
Beaver Dam Wash Bridge Hydrology Report	Mohave County, URS - July 2005	These two reports include hydrology and hydraulic analysis for bridge replacement at Beaver Dam, AZ	http://www.co.mohave.az.us/pw/Flood%20Control/BeaverDam%20Data.htm
Beaver Dam Wash Bridge Hydraulic Report	Mohave County, URS - July 2005	These two reports include hydrology and hydraulic analysis for bridge replacement at Beaver Dam, AZ	http://www.co.mohave.az.us/pw/Flood%20Control/BeaverDam%20Data.htm
Mohave County Flood Control Ordinance-2000	Mohave County Flood Control District	County flood control ordinance	Mohave County Flood Control District
Nevada			
Mesquite Flood Control Master Plan Update (MPU)	Clark County Regional Flood Control District, 2007	The 2007 MPU serves as a planning tool for the implementation of the flood control system in Mesquite and for the design and construction of master plan facilities. The flood control system identified and described in this MPU may be subject to further amendments and revisions in the future as more detailed analyses are completed for facilities in the pre-design and design phases.	http://breccia.ccrfcd.org/FileLibrary/FileLibrary.aspx
Town of Bunkerville Flood Control Master Plan Update	Clark County Regional Flood Control District, 2007	The 2007 MPU is a planning tool for use by public agencies, land planners, and various other entities. It provided updated information concerning the comprehensive flood control plan. The document presents information and analyses that went into the update. Bunkerville is impacted by several washes that discharge to the Virgin River.	http://breccia.ccrfcd.org/FileLibrary/FileLibrary.aspx
Draft Conceptual Framework for Development of the Virgin River Flood Control and Restoration Measures Long-Term Plan	City of Mesquite, Mar 2005	The goals are to reduce the risk of flooding to structures and infrastructure within City of Mesquite, to reduce the potential for lateral and vertical channel instability and resulting erosion of stream banks during high-flow events that can threaten homes, land and infrastructure, and to restore natural fluvial processes in order to provide appropriate aquatic and riparian critical and optimal habitat for listed species.	City of Mesquite

Virgin River Flood Insurance Study, Request for LOMR	Clark County Regional Flood Control District, May 2006	Area experienced a major flood event near the magnitude of a 0.01 frequency event in January, 2005. During this event, the flooding limits were wider than the mapped 100-year regulatory Special Flood Hazard Area, which caused more than $1 million in public infrastructure damages and damaged approximately 80 homes. Therefore, this LOMR recommends needed revisions to the existing FEMA flood zone delineation shown on the Flood Insurance Rate Maps (FIRMs) for the City of Mesquite and Clark County.	http://breccia.ccrfcd.org/FileLibrary/FileLibrary.aspx
Virgin River Flood Study, Geomorphic Analysis Report Virgin River at Mesquite	Clark County Regional Flood Control District, Oct 2006	Analyzes the river's response to the January 2005 floods in the context of historical information, synthesizes this information to provide insight into potential future behavior of the river system, and provides recommendations for future river management practices.	http://breccia.ccrfcd.org/FileLibrary/FileLibrary.aspx
Virgin River Flood Hazard Study: Erosion Protection Report	Clark County Regional Flood Control District, January 2007.	Report presents alternatives forf algnment of potential erosion protectoin including bank protection and other structuresalong the Virgin River in the vicinity of Mesquite and Bunkerville, NV.	http://breccia.ccrfcd.org/FileLibrary/FileLibrary.aspx
Clark County Hydrology and Drainage Design Manual	Clark County Regonial Flood Control District, 1999 with revisions	The purpose of the MANUAL is to provide a minimum standard for analysis and design of storm drainage facilities within the CCRFCD. Provision of the minimum standard assures that all drainage facilities are consistent in design and construction, and provides an integrated system which acts to protect the public health, safety, comfort, convenience, welfare, property and commerce.	http://breccia.ccrfcd.org/FileLibrary/FileLibrary.aspx
Post-Fire Flood Hazard Assessment Meadow Valley Wash and Beaver Dam Wash	BLM, September 2007	Study purpose was to assess changes to runoff, erosion and sedimentation resulting from 2005 and 2006 wildfires. Study area includes a portion of Meadow Valley Wash and Beaver Dam Wash (Virgin River Watershed). Study area includes Nevada and Arizona but most of the focus was on Meadow Valley Wash.	BLM
Southern Nevada Fire Complex June/July 2005 BAER Plan	BLM, 2005	Report of the National Interagency Burned Area Emergency Response Team assessing the large Southern Nevada complex fires. Discusses and maps burned area, post fire conditions, and risks.	BLM

Utah			
River Stability Study, Virgin and Santa Clara Rivers	Washington County, City of Santa Clara and City of St. George, Sept 2005	In response to the damaging floods in January 2005, completed a river stability study as part of a Master Plan, which included a geomorphic evaluation of the Santa Clara and Virgin Rivers. The report concludes with five recommendations, mostly focused on land use.	http://wcwcd.state.ut.us/
Fort Pearce Wash Master Plan: A roadmap for reconstruction, management, and long term maintenance.	Washington County Water Conservancy District. April 2007	Extreme flooding in Washington County and Southern Utah during January 2005 revealed potential vulnerabilities to flood and erosion hazards and highlighted the need for coordinated master planning along the major river systems. Plan goals are to optimize the function and stability of Fort Pearce Wash in order to minimize risk of erosion and property damage from future floods.	http://wcwcd.state.ut.us/
Fort Pearce Wash River Mining Plan	Washington County Water Conservancy District. March 2007	As part of the Maser Plan this document is intended to assist establishment of mining guidelines to be used to regulate instream mining primarily along Ft. Pearce Wash and to assess likely impacts to flood and erosion hazards along the wash corridor. Objectives are to allow for the production of aggregate while minimizing the potential for flood and erosion damages to the local community and to the environment.	http://wcwcd.state.ut.us/
Virgin River Stability Study Update	Washington County Water Conservancy District. March 2007	As part of the Maser Plan this document consisted of a geomorphic evaluation of the Virgin River from its confluence of the Santa Clara River to the Washington Fields Diversion Dam. It extends erosion hazard delineations previously determined in a 1997 study.	http://wcwcd.state.ut.us/
Master Plan: A road map for reconstruction, management, and long-term maintenance. Santa Clara River, Washington County, Utah	Washington County Water Conservancy District. September 2005	The primary goal of the Master Plan is to minimize the risk of flooding and bank erosion along the Santa Clara and Virgin Rivers. AThe Master Plan recommends specific protocols for the reestablishment of stream channel, floodplain, and terrace features; revegetation of the riparian areas for stability and wildlife; address appropriate future land use along the rivers; and recommend a long-term maintenance program to ensure project objectives are achieved.	http://wcwcd.state.ut.us/
Virgin River Master Plan: A road map for reconstruction, management, and long-term maintenance. Virgin River, Washington County, Utah	Washington County Water Conservancy District. Revised July 2007	The Master Plan goals are to optimize the function and stability of the Virgin River in order minimize risk of erosion and property damage from future floods. It recommends specific stream stability protocols for the reconstruction of stream channel, floodplain, and terrace features; revegetation of the riparian areas for stability and wildlife; appropriate future land use along the rivers; and a long-term maintenance program to ensure project objectives are achieved.	http://wcwcd.state.ut.us/

Five County Association of Governments Natural Hazard Mitigation Plan A Regional Approach for Southwestern Utah	Five County Association of Governments	The goal of this plan is to assist the five counties of Southwestern Utah, in reducing the costs of natural disasters; namely Wildfire, Landslide, Flood, Earthquake, Volcanoes, Drought, Problem Soil, Severe Weather, Insect Infestation, and, Radon Gas through mitigation practices. This plan provides comprehensive hazard identification, risk assessment, vulnerability analysis, mitigation actions, and implementation schedule for the region.	http://des.utah.gov/nathaz/pdm_pub_st.htm
Flood in Virgin River basin, Southwestern Utah, January 9-11, 2005	USGS, 2006 Online	Estimates of instantaneous peak discharges at U.S. Geological Survey (USGS) streamflow-gaging stations for the Virgin River Basin flood of January 9-11, 2005, are provided below. Recurrence interval discharge estimates were computed for each streamflow-gaging station by using two techniques.	http://ut.water.usgs.gov/FLOODING/Virgin_flood.htm
Flooding and Stream flow in Utah during water year 2005	USGS, 2005	The 2004 and 2005 water years illustrate why water managers in Utah generally describe the water supply as ‘feast or famine.’ In September 2004, Utah was finishing its sixth year of drought. The 2005 water year brought with it a significant change in the weather, beginning with intense rainfall in the Virgin River basin of southwestern Utah. Only minor flooding resulted from this storm; however, it provided soil moisture that would contribute to severe flooding during January 2005.	http://pubs.usgs.gov/fs/2006/3085/
Flood Plain Information - Virgin River and Fort Pierce Wash, Vicinity of St. George	US Army Corps of Engineers (USACE) Apr 1973	Identifies areas that are subject to future flooding for consideration in land use planning.	USACE
Hydrology for Evaluation of Proposed Water Supply Reservoirs	USACE, Aug 1988	Presents reconnaissance level hydrology examining the incidental flood control of two proposed water supply reservoirs in the Upper VR watershed.	USACE
Virgin River and Tributaries at St. George, Utah, Section 205 Reconnaissance Study	USACE, May 1991	Considers several alternatives to eliminate or reduce these damages, including, floodproofing structures at risk, installing FWS, constructing earth levee system, modifying existing channel and constructing detention basin upstream of at risk area.	USACE
North Fork of the Virgin River Town of Springdale, Utah Section 206 - Special Study Floodplain Mgmt Services	USACE, Jan 1996	Provides hydrologic, hydraulic & nonstructural flood plain information for local official use in planning and regulation of the flood plain.	USACE

LAND USE PLANNING RELATED REPORTS			
Report	**Author//Date**	**Description**	**Availability**
Proposed Las Vegas Resource Management Plan and Final EIS	Bureau of Land Management, May 1998	Outlines the various decisions for management of renewable & non-renewable resources on approximately 3.3-million acres of public land in Clark and southern Nye Counties. This includes a portion of the lower watershed within Clark County.	http://www.blm.gov/nv/st/en/fo/lvfo/blm_programs/planning/las_vegas_field_office.html
City of Mesquite, Nevada Land Sale Environmental Assessment	Bureau of Land Managment, May 2002	This EA assesses 10,620 acres of undeveloped federal land within the vicinity of Mesquite, NV proposed for sale to City of Mesquite and developers.	http://gis.fargeo.com/vrhcrp/
Kanab Draft RMP/EIS	Bureau of Land Management, 2007	The BLM is in the process of completing a RMP for the lands managed by the Kanab Field Office. This includes a portion of the watershed in Kane County. The RMP will explain current management situations, desired future conditions to be maintained or achieved, management actions necessary to achieve objectives, and a schedule and cost estimate for implementing the actions for achieving those goals.	http://www.blm.gov/ut/st/en/fo/kanab/planning/draft_rmp_eis.html
Proposed Resource Management Plan/Final Environmental Impact Statement for the Arizona Strip Field Office	Bureau of Land Management, March 2007	This plan covers a large portion of the watershed under management by the BLM within Arizona. It mainly addresses issues related to access, wilderness, protection of natural and cultural resources, livestock grazing and recreation.	http://www.blm.gov/az/st/en/prog/planning/strip/reports/FEIS.html
St. George Field Office Record of Decision and Resource Management Plan	Bureau of Land Management, March 1999	This document describes the management decisions approximately 629,005 surface acres and 671,545 total acres of federal mineral estate administered by the BLM under the St. George Field Office in St. George, Utah. This includes a significant portion of the watershed within Washington County, Utah.	http://www.blm.gov/style/medialib/blm/ut/natural_resources/planning/existing_lups.Par.33976.File.dat/STGEOROD.PDF
Land and Resource Management Plan for the Dixie National Forest and EIS	USDA Forest Service, 1986	The plan is a guiding document describing standards and guidelines for all resource management activities within the forest. While it provides guidelines, the individual projects or activities are dependent on annual budget and not specifically addressed. An EIS is associated with this plan. Approximately 7% of the watershed is within Dixie National Forest, mostly in Washington County and Santa Clara River watershed.	http://www.fs.fed.us/r4/dixie/projects/lmp/fpr/Documents/index.shtml#dxlrmp
Proposed Land Management Plan for the Dixie and Fishlake National Forests	USDA Forest Service, 2006	This Draft Land Management Plan updates the plan listed above. It describes strategic direction and provides broad, program-level guidance for managing the land and resources of the Dixie and Fishlake National Forests.	http://www.fs.fed.us/r4/dixie/projects/lmp/docs/plmp/start_here.pdf

Zion National Park General Management Plan	National Park Service, August 2001	The plan is intended to provide a general path the National Park Service intends to follow in managing Zion National Park over the next 20 years. The plan will provide a framework for proactive decision making on such issues as visitor use, natural and cultural resource management, and park development, which will allow park managers to effectively address future problems and opportunities.	http://www.nps.gov/zion/parkmgmt/upload/zion_gmp.pdf
Vision Dixie	Preliminary restults, meeting information, and maps can all be located on the website.	Vision Dixie is an initiative in Washington County, UT to help describe a local vision for future development in the county. It has been completed through a public planning process seeking input from the community in a facilitated conversation about growth, gathering their ideas, employing sound data and scenario analysis, and outlining publicly supported principles to guide future land use and transportation decisions.	http://www.visiondixie.org/
The Five County Association of Governments Consolidated Plan	Five County Association of Governments, 2005	The FCAOG covers five southwestern Utah counties: Beaver, Garfield, Iron, Kane and Washington, This plan documents the housing, community, economic development, homelessness and other special needs in southwestern Utah and is updated annually. It includes an analysis of planning and development needs for the affected communities as well as capitol improvement plans, both 1 and 5 year.	http://www.fcaog.state.ut.us/dep/community/consolidated.php
Virgin River Communities Area Plan	Mohave County, Arizona 1998	This Area Plan focuses on the growth of the Virgin River Communities through the year 2020. These communities include Scenic, Arvada, Littlefield and the Beaver Dam and Desert Springs areas. They intend to form a single incorporated city in the next five to ten years, with a projected population reaching 25,000 or more by 2020. Until this is accomplished, the Area Plan will ensure that growth in the area is consistent with the communities' shared vision of the future.	http://www.co.mohave.az.us/depts/pnz/pnz_default.asp
Mohave County General Plan	Mohave County, Arizona updated 2005	As a General Plan, this document provides a basis to guide decision-makers. In addition to defining the County's view of its future it establishes policies and programs to address the many issues facing the County.	http://www.co.mohave.az.us/depts/pnz/pnz_default.asp
Ely Proposed Resource Management Plan Final Environmental Impact Statement	BLM. 2005	This RMP includes the portion of the watershed in extreme southeast Lincoln County, NV.	http://www.blm.gov/nv/st/en/fo/ely_field_office/blm_programs/planning/ely_rmp_2007.html
Clark County Comprehensive Plan	Clark County, NV	The Clark County Comprehensive Plan is a long-term general policy plan for the physical development of unincorporated Clark County. The Comprehensive Plan is a compilation of individual documents called "elements." Policies for each element are in the Comprehensive Plan. The Northeast section of the county falls within the watershed including Mesquite, Bunkerville and Riverside.	http://www.co.clark.nv.us/Comprehensive_Planning/ComprehensivePlanning.htm

Invasive Species Related Reports			
Report	**Author//Date**	**Description**	**Availability**
Special Report Lower Virgin River Vegetative Management and Efficient Use Program	US Bureau of Reclamation, 1985	Pilot study developed by USBR to determine the consumptive water use of phreatophytes on the Lower VR between 1982 and 1985 and how much water could be conserved by their removal and possible replacement with other lower consumptive use vegetation.	http://gis.fargeo.com/vrhcrp/
An Ecological Evaluation of the Lower Virgin River Riparian Corridor	Southern Nevada Water Authority, March 2001	Primary goals of this study were to describe vegetation communities to determine how the different communities are used by wildlife and to predict how the distribution and composition of vegetation and wildlife communities change with VR flow levels.	http://gis.fargeo.com/vrhcrp/
BLM Healthy Forest Initiative Update	BLM, 2005	Lists accomplishments made since Healthy Forest Initiative (HFI) enactment, 8/23/2003.	http://gis.fargeo.com/vrhcrp/
Salt Cedar Removal and Revegetation on the Virgin River –Draft Plan	Clark County Desert Conservation Program, 2005?	Monitoring programs focus on two goals: 1) restoring native plants, wildlife habitat and hydrologic function and 2) evaluating the effects of saltcedar control and native plant restoration treatments	http://gis.fargeo.com/vrhcrp/
Environmental Assessment Wildland Urban Interface Hazardous Fuels Reduction Program On the Virgin River, Clark County, Nevada: City of Mesquite Tamarisk Treatment Project JE25	Bureau of Land Management	In Southern Nevada, the communities of Bunkerville, NV and Mesquite, NV encompass a 10-mile-long wildland-urban interface along the Virgin River. Tamarisk has invaded the river floodplain and poses a serious fire fuels threat to these communities. Because of the density of tamarisk along this floodplain, wildfires frequently occur in the riparian corridor. The desired condition to be achieved is a riparian river corridor along the urban interface where the density of tamarisk is greatly reduced as a hazardous fuel and replaced by native riparian vegetation.	BLM-Las Vegas
Tamarisk Removal Activities in the Virgin River Watershed: Lower Virgin River Fuels and Fire Council	Corey Cram, Washington County Water Conservancy District, January 2007	Paper describes the Virgin River and tamarisk removal activities/options with focus on the vicinity near St. George, UT	Washington County Water Conservancy District
2004 Lower Colorado Region Vegetation Type Mapping, Backwaters Delineation, Orthophotography, and GIS Development	U.S. Bureau of Reclamation	This project is part of an ongoing effort to protect endangered species and native habitat. The report included vegetation mapping on the Lower Colorado River and several tributaries including the Lower Virgin River.	U.S. Bureau of Reclamation

Water Supply Related Reports			
Report	**Author//Date**	**Description**	**Availability**
Hydrology and Interactive Computer Modeling of Ground and Surface-Water in the Lower Virgin River Valley	Las Vegas Valley Water District, 1992	Objectives include: 1) update land use and ground-water level data, 2) compile and review all available data 3) interpret these data and define the hydrologic characteristics of the basin, 4) inventory all existing and pending water rights permits and applications, and 5) prepare a computer model to simulate ground- and surface-water flow in the basin and to evaluate the potential impacts of proposed District withdrawals.	http://gis.fargeo.com/vrhcrp/
Lower Virgin River Project Management Report in Support of Water Rights Application Numbers 54077, 57643 and 58591	Las Vegas Valley Water District and Southern Nevada Water Authority (SNWA), Nov 1993	Purpose is to demonstrate the Las Vegas region's need for VR water and to develop a configuration for the Lower VR Project that is capable of diverting and transporting to the LV Valley the available unappropriated water in the Lower VR at Halfway Wash in an environmentally responsible way.	http://gis.fargeo.com/vrhcrp/
Addendum to Environmental Report of the Virgin River Water Resource Development Project	Las Vegas Valley Water District, 1993	Addresses expected project effects that are different from those in the 1989 (amended '92) application for Virgin River water.	http://gis.fargeo.com/vrhcrp/
Concepts for Development of Additional In-State Water Resources	SNWA, Feb 2004	This document presents the proposed development of in-state, non-Colorado River water resources forming a part of the portfolio of potential additional water resources identified in the SNWA.	http://gis.fargeo.com/vrhcrp/
Inventory of Reservoirs and Potential Damsites in the Virgin River Basin	Utah Division of Water Resources, Dec 1988	Summary of existing reservoirs and previously investigated damsites and reservoirs in the VR basin in Utah.	UT DWR
Lake Powell Pipeline Project	State of Utah	The Lake Powell Pipeline project is currnently being studied. Water development projects in Washington County, Kane County and Iron County will only be able to meet the growing demand for water until about 2020. The proposed project will eventually take water from Lake Powell, near the Glen Canyon Dam, and transport it to Washington, Kane and Iron counties.	http://www.lakepowellpipeline.org
Geology and Hydrology of the Lower Virgin River	Virgin Valley Water District	Defines the water resources available to the VVWD, this includes a comprehensive geologic and hydrologic evaluation of the VR and the lower VR Valley ground-water	Virgin Valley Water District

Valley in Nevada, Arizona and Utah	(VVWD), 2002	system.	
Utah State Water Plans	Utah Division of Water Resources	Utah DWR has prepared several reports titled "Utah State Water Plan.", all of which are available online. These include a statewide water plan and an individual water plan for each of the state's eleven major river basins. In addition to the most recent State plan, Utah's Water Resources Planning for the Future (2001) several other reports are specific to conjunctive management, drought, and water reuse.	http://www.water.utah.gov/waterplan/
Kanab Creek/Virgin River Basin State Water Plan	Utah Division of Water Resources, August 1993	The subject basin plan disucsses the Virgin River Basin and associated water resouce issues. Although there have been significant changes since the plan was published in 1993 much remains consistent and has been updated in related water plans listed above.	http://www.water.utah.gov/waterplan/
Nevada State Water Plan	Nevada Division of Water Resources, 1999	The Nevada State Water Plan is designed to help guide the development, management and use of the state's water resources. The plan assesses the quantity and quality of Nevada's water resources, and identifies constraints and opportunities which affect water resource decision making. The plan looks at historical and current water use, and projects demands out to the year 2020.	http://water.nv.gov/WaterPlanning/wat-plan/con-main.cfm
Amendment to Northeast Clark County 208 Water Quality Management Plan	Clark County, NV, 2007	The main purpose of this is to acknowledge that there is a lack of wastewater management options in most northeast Clark County communities and to amend the NE WQMP primarily to allow for the option of package wastewater treatment plants (package plants) and/or interim package wastewater treatment plants (interim package plants) in those northeast communities in order that those development entities seeking to construct homes in major subdivisions at densities higher than presently exist can have the option to do so.	http://www.accessclarkcounty.com/depts/daqem/epd/Pages/water_projects.aspx
Arizona Water Atlas	Arizona Department of Water Resources, 2007	This document is in progress for the State of Arizona and being placed online as completed. The section including the Virgin River watershed was released in September 2007. The primary objectives of the Atlas are to present an overview of water supply and demand conditions, to provide water resource information for planning and resource development purposes and to help identify the needs of communities throughout Arizona, particularly those outside the AMAs.	http://www.azwater.gov/dwr/

Watershed Scale Reports

Title	Author/Date	Description	Availability
Utah State Water Plans	Utah Division of Water Resources	Utah DWR has prepared several reports titled "Utah State Water Plan.", all of which are available online. These include a statewide water plan and an individual water plan for each of the state's eleven major river basins. In addition to the most recent State plan, Utah's Water Resources Planning for the Future (2001) several other reports are specific to conjunctive management, drought, and water reuse.	http://www.water.utah.gov/waterplan/
Kanab Creek/Virgin River Basin State Water Plan	Utah Division of Water Resources, August 1993	The subject basin plan discusses the Virgin River Basin and associated water resource issues. Although there have been significant changes since the plan was published in 1993 much remains consistent and has been updated in related water plans listed above.	http://www.water.utah.gov/waterplan/
Nevada State Water Plan	Nevada Division of Water Resources, 1999	The Nevada State Water Plan is designed to help guide the development, management and use of the state's water resources. The plan assesses the quantity and quality of Nevada's water resources, and identifies constraints and opportunities which affect water resource decision making. The plan looks at historical and current water use, and projects demands out to the year 2020.	http://water.nv.gov/WaterPlanning/wat-plan/con-main.cfm
Arizona Water Atlas	Arizona Department of Water Resources, 2007	This document is in progress for the State of Arizona and being placed online as completed. The section including the Virgin River watershed was released in September 2007. The primary objectives of the Atlas are to present an overview of water supply and demand conditions, to provide water resource information for planning and resource development purposes and to help identify the needs of communities throughout Arizona, particularly those outside the AMAs.	http://www.azwater.gov/dwr/
Upper Virgin River HUC - (15010008) Rapid Watershed Assessment	USDA-NRCS, March 2007	A Rapid Watershed Assessment (RWA) is a set of initial estimates of where conservation investments might best address local resource concerns. The information is intended to be used along with other relevant information to assist individuals, communities, non-profits, local, state and federal entities and others to evaluate future conservation activities on a watershed basis.	http://www.ut.nrcs.usda.gov/programs/RWA/index.html
Virgin River Watershed Management Plan	Virgin River Watershed Advisory Committee, 2006	This plan was developed for the Upper watershed within Utah and is intended to be an evolving plan that prioritizes problems or needs within the watershed. It Includes a list of recommended project priorities by sub basin throughout the watershed. It is an updated and more detailed plan than the one that is supersedes (1998), available at the same website.	http://wcwcd.state.ut.us/
Virgin River Basin- Utah Cooperative Study	USDA, NRCS and Utah DWR, 1990	The study was conducted to assist agencies in planning efforts and to conserve, develop and coordinate resources to meet future needs. It addresses economics, recreation, water supply, erosion and floodplains, rangeland, cropland, and wildlife.	See agencies for availability

Appendix B:
Virgin River and Tributaries Floodplain Management Strategy

Provided Electronically on CD. See folder *Appx B Floodplain Strategy*

Virgin River Watershed Study

Tamarisk Toolbox

(Photo taken from BIO-WEST, Inc. 2006)

Prepared by

US Army Corps of Engineers®
Albuquerque District

October 5, 2008

Table of Contents

Figures and Tables

I. Purpose of Document

This document was written as one of the issues for consideration in the Virgin River Watershed Study. This document is meant to bring together information regarding current efforts to address salt cedar (*Tamarix* spp.) management, treatment, and/or prevention in the Virgin River Watershed. It is a starting point to bring together both the collaborators and the information available (at this current date) in order to move ahead with a concerted watershed focused effort on the issue of salt cedar management. It is hoped that this document will be the first step toward a larger concerted effort in the watershed. It provides information on current treatments (the tools in the toolbox) and potential funding avenues for future work.

II. Introduction

There have been significant changes in plant communities along rivers in the southwest since the early 1900s. This is due, in part, to the introduction of exotic plant species, particularly saltcedar (*Tamarix* spp.), also called tamarisk. The spread and abundance of saltcedar has been accelerated by management actions that have disturbed these river systems (Parker et al., 2005; Stromberg et al., 2005). These management actions include changes to the hydrology and geomorphology of these rivers, for instance, peak flow attenuation, channel narrowing and channel incision. River regulation and geomorphic alterations, combined with seed source availability, has allowed saltcedar and other non-native vegetation to spread into many areas and in some situations, compete with the native vegetation.

The Virgin River Watershed is one of these southwestern systems to be affected by the invasion of saltcedar. The history of the Virgin River tamarisk conversion is well documented (Heap 1854; Remy & Brenchley 1861; Merriam 1893; Larson 1961; Christensen 1962; Jackson & Spence 1973; Fletcher 1980; Hughes 1993). On most U.S. rivers tamarisk invasion is linked to alteration of in-stream flow dynamics or flood regimes, via impoundment, diversion or other means, as mentioned above. In the Virgin River watershed factors contributing to saltcedar invasion include, but are not limited to, land conversion; agricultural clearing and plowing; groundwater drawdown (Shrader 1977), (Engel-Wilson & Ohmart 1978); livestock over-grazing (Hughes 1993); the intentional planting of tamarisk to stabilize over-grazed and/or eroding streambanks (Everitt 1980), and over-harvesting of cottonwood, mesquite, and other larger native riparian shrubs and trees for fuel wood and building materials by pioneer settlers and townships (Horton 1977), (Brotherson & Winkel 1986). This background information specific to the Virgin River Watershed was taken from BLM, 2003. Another factor contributing to the establishment of saltcedar is the relocation of the channel periodically due to large flows. Formation of these new channels, along with the abandonment of the previous channel, provide opportunities for plant establishment (Stromberg and Patten, 1994), including saltcedar.

Taxonomy

Saltcedar is a deep-rooted deciduous shrub or tree that can grow up to 25 feet tall (Parker et al., 2005). It was originally introduced from Eurasia for erosion control. It is widely distributed throughout the West and surveys estimate that over 1.5 million acres are populated with saltcedar in the southwest (Brock, 1994). Spread of saltcedar is through seed dispersal but the species can also propagate vegetatively. In arid and semiarid regions, it is found in areas with relatively high water availability such as river banks and reservoir margins (Brock, 1994).

Most of the introduced species of *Tamarix* naturalize only weakly in North America (Dudley *et al* 2001). However, four of the five species exhibit weedy life habits under the human-disturbed riparian habitat conditions found today in the western half of the U.S., particularly in the arid, water over-exploited and fast-developing Southwest. This disturbance-state ecological setting, in synergism with related and unrelated competitive release factors on the part of native riparian plant species, has allowed these weedy trait *Tamarix* species to become invasive. The four species (*T. chinensis; gallica; parviflora*; and *ramosissima*) are difficult to differentiate, either based on geographic distribution or gross morphology (*T. chinensis* is slightly taller) (Di Tomaso 1998). The dominant species within the Virgin River watershed is considered as *Tamarisk ramosissima,* and *T. parviflora* also exists in some areas (T. Dudley, pers. comm.).

Summary of impacts

Saltcedar has been targeted by management agencies for control or removal throughout the southwestern United States. Justifications for these large-scale control projects vary, but commonly include concerns that saltcedar increases groundwater consumption, increases soil salinity, decreases wildlife habitat quality, increases propensity for flooding and/or fire, and proliferates following floodplain fires.

Once established, tamarisk tends to form dense, monotypic thickets of uniform canopy height. Not only does this displace the standing native plants, but the characteristic lack of bare ground and rapid, deep accumulation of tamarisk leaf litter offers little or no germination opportunity for the seeds of native species (Horton 1977). The resulting habitat is of significantly reduced value to all but a few faunal species (Kerpez 1987), and entails the loss of native plant community and species diversity; vegetative structural height and complexity, and species richness and abundance. Saltcedar often supports a lower population of arthropods—a main food source for birds—than native riparian vegetation such as cottonwood (*Populus* spp.) and willow (*Salix* spp.) (Shafroth et al., 2005).

The Virgin River watershed is mostly free of human alterations that can further exacerbate the invasion of salt cedar (such as levees and dams) though it does have flood control features in some locations as well as development along populated corridors of the watershed. In these locations, where the channel is constricted in combination with nearby communities, flooding and fire risks are increased by dense stands of saltcedar along the banks of the river.

Increased fire frequency and severity in densely vegetated floodplains near the urban interface has become a serious concern in many southwestern watersheds. Compared especially to native cottonwood, saltcedar responds favorably to fire and legitimate concerns exist that fires in mixed native and exotic vegetation have the potential shift to exotic dominance. Whether saltcedar dominates a previously mixed stand following a fire may depend upon a variety of issues, including fire temperature, fuel load characteristics, depth to groundwater or other site characteristics.

Therefore, the overall management of saltcedar can help reduce flooding and fire risk as well as favor establishment of native vegetation (in a less dense form) when restoration is included in the management.

Major Issues for the Virgin River Watershed

A. Fire – Fire has occurred in areas throughout the watershed. The following is a summary of some of the fire history though it does not include all of the fire history for the entire watershed.

Utah –

A Lower Virgin River Fuels and Fire Plan (LVRFFP) was completed for Washington County (SWCA, 2005). This Plan was developed in recognition of the existing potential for fire in tamarisk stands of the Lower Virgin River and was funded by the Utah Division of Forestry. Appendix G of this plan gives an overview of the fire history for the past 20 years in the Plan area which includes portions of the communities of Bloomington, the City of St. George and Washington City. Since 1988, 64 fires occurred within this portion of the watershed and 23 of these were ‘wildland’ fires presumably in the riparian area. The LVRFFP prioritizes areas for tamarisk removal in order to aid in fire prevention.

Nevada –

The series of fuel reduction projects that stemmed from fire rehabilitation, has expanded into 1300 acres under treatment for tamarisk abatement, stretching 15 miles into Nevada from the Arizona border. These treatments focus on reducing the historic wildfire threat introduced by the dense and highly flammable tamarisk stands near the populations of Mesquite, Riverside, and Bunkerville, NV. The Bureau of Land Management (BLM) has been working on restoration of fires that occurred since 2001. These fires are described as follows and high density of saltcedar attributed to the fuel for the fires. Project JE25 is the restoration of a fire that occurred on September 16, 2001 and burned 135 acres (Tim Rash, personal communication). JE25 is approximately 1/4 mile upstream of State Route 160 Riverside Bridge and four miles below the outskirts of the Bunkerville-Mesquite wildland urban interface zone; T14s, R70E, Section 7. BLM is also working on the restoration of another fire area called Project JE22. This fire burned 10.3 acres on June 2, 2002 and is 3.4 miles below State Route 160 Riverside Bridge; T14S, Sec. 28 NE SE (BLM, 2003).

Though more fires have occurred within the watershed and some may be due to the high saltcedar densities, the above information gives examples of how critical it is to address fire prevention within the watershed. The LVRFFP does just this but that is for only one county within the watershed. This issue needs to be looked at in greater detail throughout the watershed and evaluated to the same level as the LVRFFP in order to determine high priority areas for fuel reduction, specifically thinning and removal of saltcedar.

B. Flooding – The most recent flooding that occurred within the watershed occurred in 2005 and 2007. The major effects from the 2005 occurred in the Santa Clara River, there were also impacts in the City of St. George and as far downstream as Clark County, NV. These events and their impacts are described in detail in The Virgin River and Tributaries Floodplain Management Strategy (VRFPMS) (JE Fuller Hydrology and Geomorphology, Inc., 2007) prepared as part of this study. The presence of saltcedar in the watershed added to the flood impacts due to the fact that dense stands can substantially reduce conveyance capacity of an active river channel during these large magnitude floods. Though the floods can also aid in the removal of saltcedar (for example, the 2005 flood removed all of the saltcedar in the Santa Clara River within City of St. George (Randy Halverson, pers. comm..), management of it prior to floods can help reduce the impacts of high flows in the future. Further description of the increased flood and fire threats due to dense saltcedar stands is further discussed in the VRFPMS.

III. <u>Current saltcedar management efforts in the watershed</u>

A. Current efforts

Numerous efforts to remove, control and/or manage saltcedar in one way or another as well as restore areas after removal are taking place throughout the watershed. An inventory of current efforts was conducted and work areas are shown on Figure 1. Work within each state is described below.

<u>Utah</u>

In the state of Utah, the majority of efforts to inventory and manage saltcedar have been in and around the City of St. George which is in Washington County. As discussed above, this is where the floods of 2005 caused considerable damage. Saltcedar along the banks of the river exacerbated the flood effects. Since that time, the City of St. George has been working to remove saltcedar and restore areas where saltcedar was removed by the flood. In the Santa Clara River, all saltcedar has been removed within the City limits (R. Halverson, pers. comm.). In the Fort Pearce Watershed, approximately 2/3 of the saltcedar has been removed. Along the Virgin River proper, the City, working with the Utah Department of Natural Resources, is removing 100 acres of saltcedar in the St. James area where there is a high risk of fire. They have also cleared about 10 acres in the Sand Hollow Wash which dumps into the Santa Clara River. Overall, the city has cleared approximately 1500 acres of saltcedar (see Figure 2) and continues to look for ways (funds and other assistance) to continue removal as well as restoration. They are also involved with the Virgin River Program which includes Utah Division of Forestry Fire and State Lands and the Washington County Water Conservancy District. The goal of this Program and these three agencies working together is to remove tamarisk sprouts from new point bars that have developed and instead establish native vegetation on them (Cram, 2007).

There has also been a recent release of *Diorhabda elongata* (discussed further in Section V) as a potential treatment of salt cedar. Three locations just south of Bloomington have been set up as research sites. The research effort is being headed up by the U.S. Department of Agriculture Health Inspection Service (APHIS) in cooperation with the Washington County Water Conservancy District and the City of St. George (Campbell, 2008). The beetle populations have also moved downriver across the northwestern corner of Arizona and into Nevada (Christian Science Monitor, 2008). Beetles have also been detected in Zion National Park and downstream to Littlefield, AZ. A survey of the watershed is being conducted to determine the full dispersal of the beetles (T. Dudley, pers. comm.). Current work is ongoing (BioControl New and Information; Dudley and DeLoach, 2004) and future work is proposed by Dudley, DeLoach and their fellow researchers.

Tamarisk and Russian olive (*Elaeagnus anguistifolia*) *treatment* has also been implemented along the mainstem of the Virgin River within the Zion National Park (ZNP) by the National Park Service (NPS) as follows (C. Deuser, pers. comm.). All initial populations of tamarisk and Russian olive have been treated along the Virgin River

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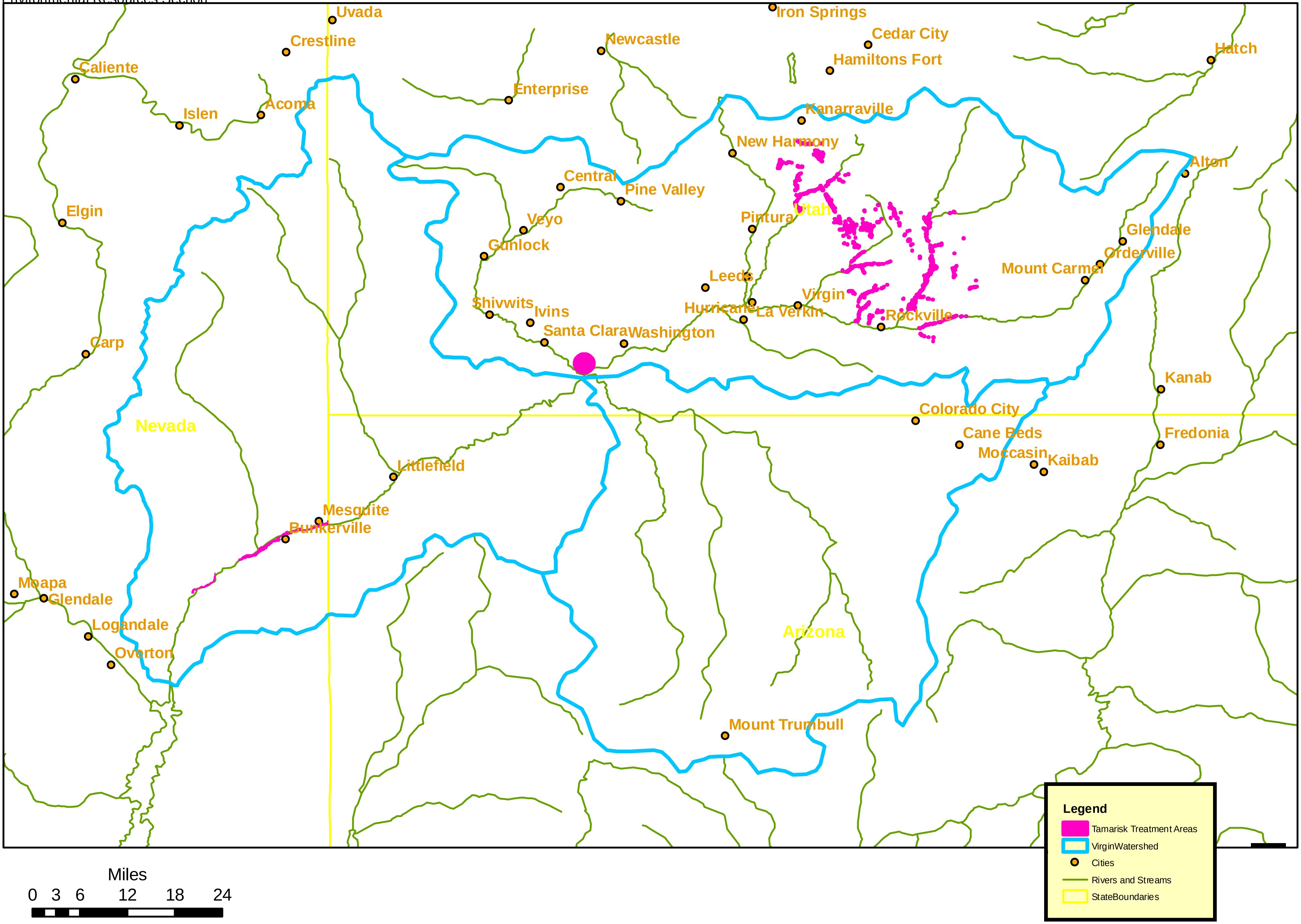
Figure 1.
Virgin River Watershed
Tamarisk Treatment Areas

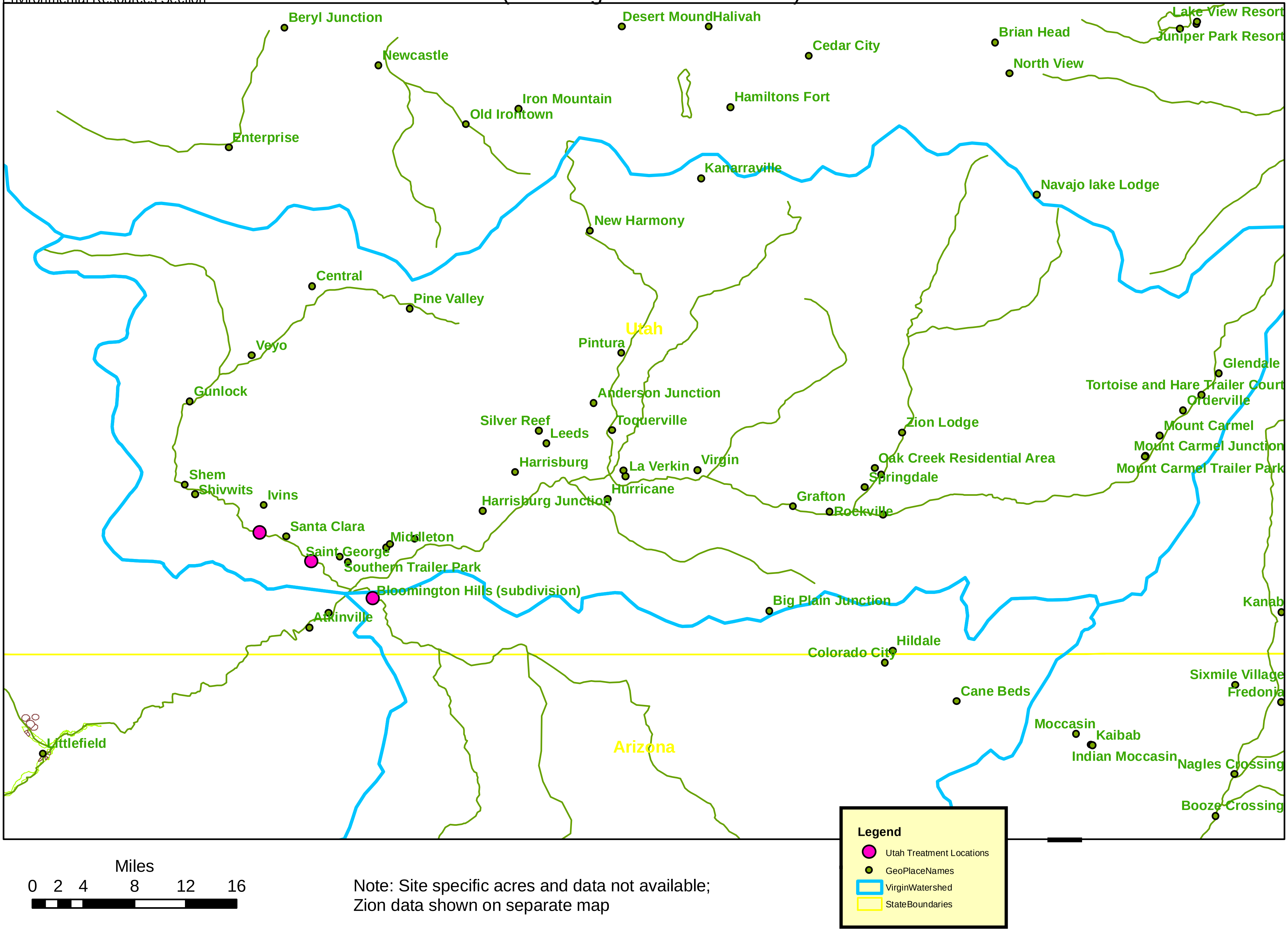
January 18, 2008



Virgin River Watershed
Saltcedar Treatments in Utah
(including beetle treatments)

Environmental Resources Section

October 3, 2008

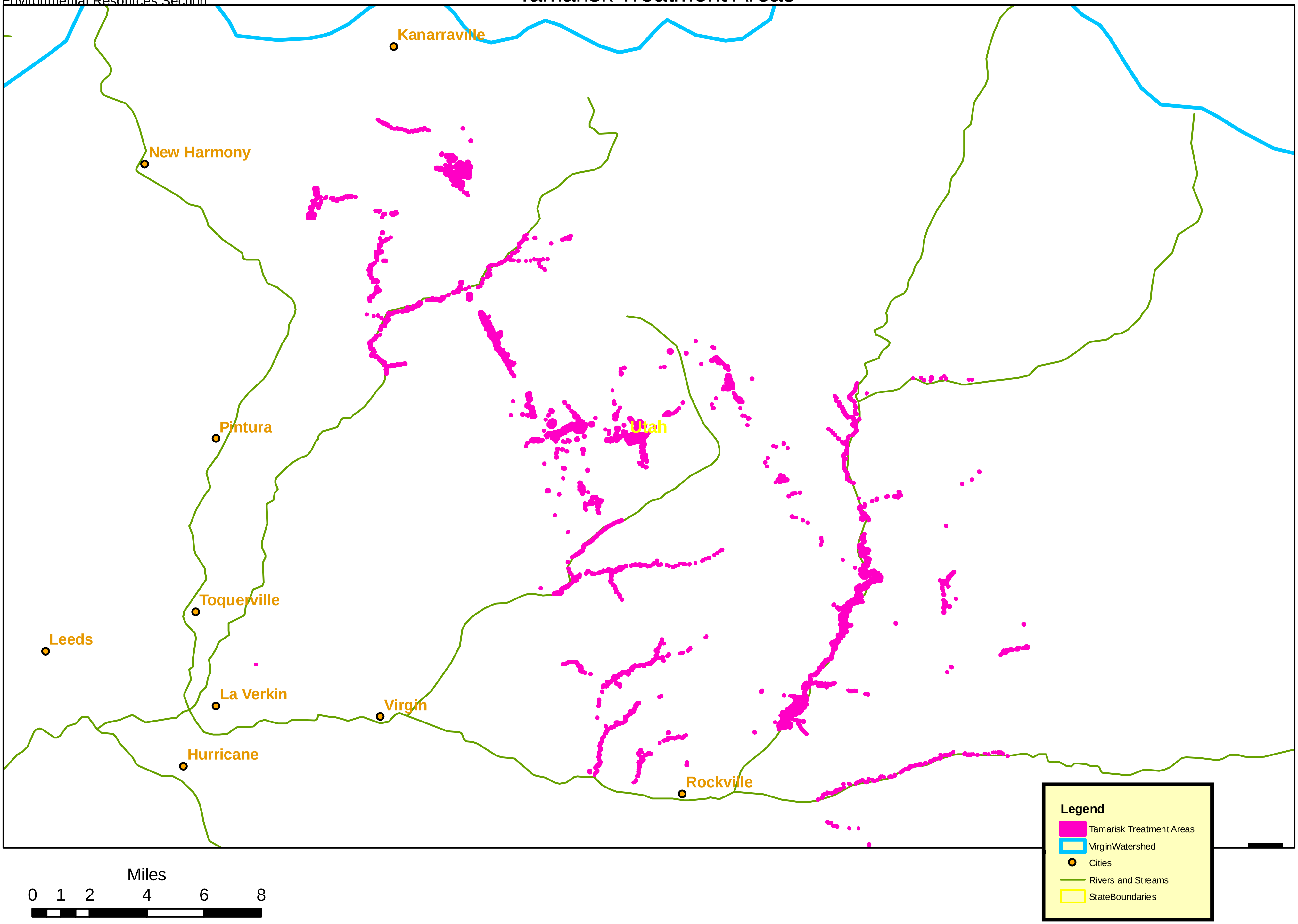


Note: Site specific acres and data not available;
Zion data shown on separate map

US Army Corps of Engineers
Albuquerque District
Environmental Resources Section

Figure 3.
Zion National Monument
Tamarisk Treatment Areas

January 18, 2008



in Zion Canyon. The area is currently in maintenance mode where retreatment occurs periodically as needed. Most of the tributaries within ZNP have also been treated. Some of the larger tributaries include Coalpits Wash, Huber Wash, Taylor Creek and others. Most of the tamarisk and Russian olive has also been cleared in the East Fork of the Virgin River within ZNP. All of these areas were once heavily infested by tamarisk and it took about 10 years of commitment to complete and less intense work for ongoing maintenance. To date, approximately 400 gross infested acres of tamarisk totaling about 100 acres of infested cover (Figure 3), have been treated. In addition 263 gross infested acres of Russian olive totaling about 1 acre of infested cover has been removed. Additional work is planned along the East Fork of the Virgin River. It should also be noted that Russian olive and tamarisk occur equally along the Virgin River from Springdale to Hurricane, UT.

There are also a number of planning documents pertinent to the Virgin River Watershed in Washington County (i.e.: Virgin River Watershed Management Plan (VRWMP), February 2006; Draft Final Report: Virgin River Master Plan (DVRMP, July 2007). Within these plans, invasive species are addressed to some degree. Vegetation management including saltcedar removal is discussed briefly in the VRWMP. The DVRMP discusses this in more detail, specifically exotic plants species removal and revegetation in specific areas. These include areas of wetland/low areas completely scoured by the river or currently being excavated, upper terrace areas where there is a mix of tamarisk/cottonwood/willows, and in areas with monotypic stands of dense tamarisk (Natural Channel Design, 2007). Long term riparian corridor monitoring and maintenance is also planned. Specific geographic locations were identified with recommendations for treatment of 'thick invasive vegetation' as well including revegetation with native species.

Other work may be occurring in the state of Utah, but it is unknown at this point in time.

<u>Arizona</u>

Related to the 2005 flood, some work to remove vegetative debris that became uprooted (including saltcedar) has occurred within the City of Mesquite in both Clark County, NV and Mohave County, AZ. Approximately 30 acres was stripped away during the flood. These areas were graded and planted with native materials (City of Mesquite, 2005).

At this point in time, no other work is occurring within the state of Arizona along the Virgin River that is known. The State of Arizona recently (June, 2008) released a statewide invasive species management plan. That plan and link to associated information can be found online at http://www.azgovernor.gov/ais/.

<u>Nevada</u>

Beginning at the AZ-NV state line heading downstream toward Hoover Dam, a large amount of work has been conducted by the Bureau of Land Management (BLM) Field Office (T. Rash, pers. comm.) (Figure 4). Approximately 20 river miles have been affected from the state line to Halfway Wash totaling approximately 1300 acres. Some of these projects were implemented post-fire (fire history is discussed above) to remove

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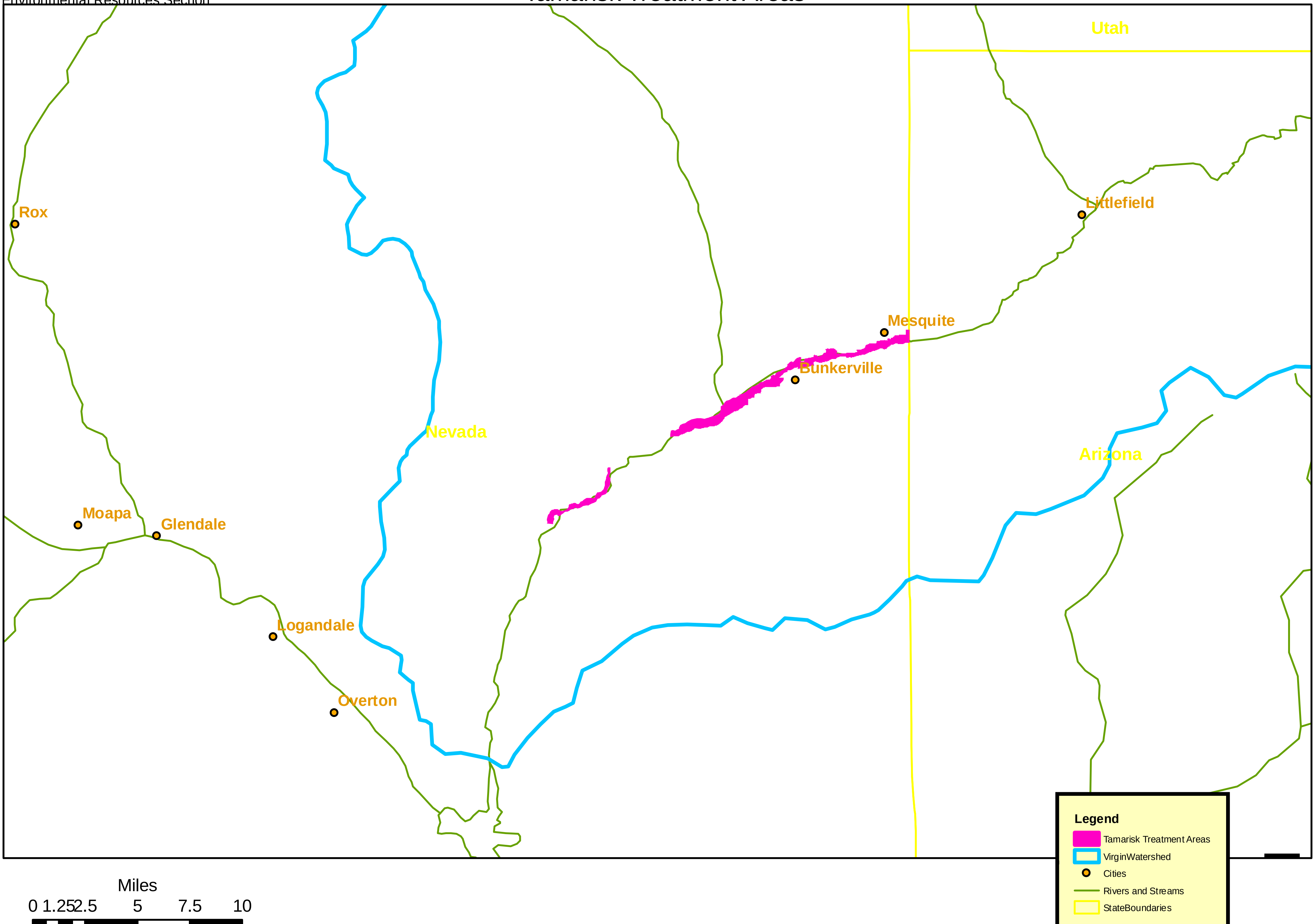
Figure 4.
Nevada
Tamarisk Treatment Areas

January 18, 2008



burned saltcedar. Other projects have been implemented to help prevent future fires and additional flood risk. The BLM Las Vegas Field Office has implemented a Hazardous Fuels Treatment Program. Information regarding specifics of these projects are referenced in the following documents: Final Environmental Assessment for the Wildland Urban Interface Hazardous Fuels Treatment Program on the Virgin River, Clark County, NV: Tamarisk Treatment Projects JE22 and JE23 (BLM, 2003), Final Environmental Assessment for the Wildland Urban Interface Hazardous Fuels Treatment Program on the Virgin River, Clark County, NV: City of Mesquite, Tamarisk Treatment Project JE25 (BLM, 2003). These areas were treated after the fires discussed in Section I above.

Planning efforts to implement these projects was done in coordination with the Vegetative Treatment on BLM Lands in Thirteen Western State, Final Environmental Impact Statement (June 1991) and the Las Vegas Resource Management Plan and Final Environmental Impact Statement (October 1998). Additional work is planned by BLM under these initiatives in order to remove, control and restore areas where saltcedar exist along the Virgin River from the state line to Halfway Wash. BLM has also been evaluating their work through the following 'effectiveness monitoring' studies: 'Restoring native plants, wildlife habitat, and hydrologic function to the Virgin River, Clark County, NV' and 'Evaluating the effects of saltcedar control and native plant restoration treatments on the Virgin River, Clark County, NV.' This information will prove useful to future treatments along the watershed and their efficacy.

The oldest tamarisk treatment and restoration site is a 75-acre site on the east side of the River on BLM Land near the town of Bunkerville, NV. This project was coordinated by an inter-agency cooperative group called "The Virgin River Tamarisk Work Group" (group) which met quarterly from approximately 1996-2000. The group was led by the Natural Resource Conservation Service (NRCS) with involvement from all levels of government. This site is fenced and signed and remains an excellent example of a once dominated tamarisk site converted to native plant dominance. The group inherited this site after a wildfire swept through the area and was completed by a grass roots effort by basal spraying the tamarisk resprouts post fire for 2-3 years, then fenced, transplanted and seeded with native plants mostly conducted by the Virgin River Tamarisk Work Group and led by BLM, NRCS, NPS and some local involvement.

Also of note is the establishment and treatment of Athel tamarisk (*Tamarix aphylla*) within Lake Mead Natural Resource Area. Thousands of athel trees established in the mid 1980s during the high water run-off from snow melt in the Rockies of 1983. This is one of the only documented occurrences of athel tamarisk establishing in the wild from seed in North America. Some of the heaviest infestations of athel tamarisk occurred in the Virgin Arm of Lake Mead and near the confluence of the Virgin River below the Mormon Mesa across from Overton, NV. The NPS is targeting eradication of this species to prevent this much larger cousin of salt cedar from spreading throughout the Colorado River watershed.

B. Extent of tamarisk throughout watershed

Utah

Though it is apparent from existing documentation developed for the watershed within the state that saltcedar is prevalent along the banks of the river, an inventory of just how much saltcedar is present in the state has not been conducted. Gross mapping by the National Institute of Invasive Species Science (NIISS, 2007) shows that the Virgin River Watershed is highly suited for tamarisk invasion and that it most likely exists along most parts of the main stem and tributaries. The level of invasion throughout the state is unclear but should be inventoried with implications for management.

A detailed analysis of vegetation was conducted for the area of Washington County with the completion of the Lower Virgin River Fuels and Fire Plan (LVRFFP) (SWCA, 2005). The riparian corridor from the Bloomington are to State Highway 9 in Washington County was evaluated. This assessment characterized species composition, relative positioning of fuel layers, and fuel density (SWCA, 2005). A ¼ mile on either side of the river was inventoried and an estimate of percent cover by species and height class. This information was then used to determine a hazard rating. Tamarisk was given its own vegetation type and a high hazard rating. This type of detailed analysis is recommended for the remainder of the watershed in Utah (and in all three states).

Arizona

A portion of the Virgin River within Arizona (approximately 10 miles) was evaluated for vegetation types between 1995-1997 (BIOWEST, 2001). Vegetation was segregated into types including 'tamarisk shrubland' and coded mapping was developed. The original mapping was not available to determine the specific amount of tamarisk within the river portion in Arizona but it appears that 'tamarisk shrubland' occurs throughout the area mapped which was from the mouth of the Virgin River Gorge near Littlefield, AZ to the state line (and from the AZ-NV state line to Lake Mead which will be discussed in the next section). For this total study area of 12,349 acres; 4,346 acres was coded as 'tamarisk shrubland' (approximately 35%). It was the predominant habitat in this portion of the lower Virgin River corridor. In 2004, the Bureau of Reclamation (BOR) performed updated vegetation type mapping of the Lower Colorado Region which included the Virgin River this same geographic area – Little Field, AZ to Lake Mead. The Anderson-Ohmart method of classification was used to classify vegetation and structure type. Classes related to saltcedar included; Salt cedar (SC), Salt cedar-Honey mesquite (SH), and Salt cedar-Screwbean mesquite (SM) (BIO-WEST, 2006). Out of the 163,678 acres that were delineated as riparian or marsh the following saltcedar acres were delineated: SC – 114,769 acres, SH – 22,160 acres, and SM – 5,680 (see Figure 5). Therefore, approximately 87% of the vegetation was coded as saltcedar or saltcedar mixed with mesquite. There is no known additional information regarding mapping of saltcedar or vegetation types for the remainder of the Virgin River in Arizona. Mapping for this portion of the river is recommended.

Nevada

The BIOWEST 2001 and 2006 reports included vegetation mapping of the Virgin River in Nevada from the AZ-NV border to Lake Mead (approximately 30 miles). As described above, ‘tamarisk shrubland’ was the predominant vegetation type in the 2001 report and saltcedar communities dominated in the updated 2004 study. The portion of the river in Nevada has the most recent and updated mapping information in relation to vegetation types and specifically saltcedar. Therefore, this portion of the river could be used as a model for information that could be collected that is currently missing for other portions of the river in other states.

Overall, saltcedar is definitely an issue throughout the watershed – along the mainstem and its tributaries. The exact amount is unknown until additional information can be obtained. It is recommended that aerial photography and vegetation mapping occur throughout the remainder of the watershed in order to determine the overall quantity of saltcedar in the watershed. Discussion of strategies for addressing it based on the geographic issue (fire, flooding, etc.) can then begin and a plan can be formulated.

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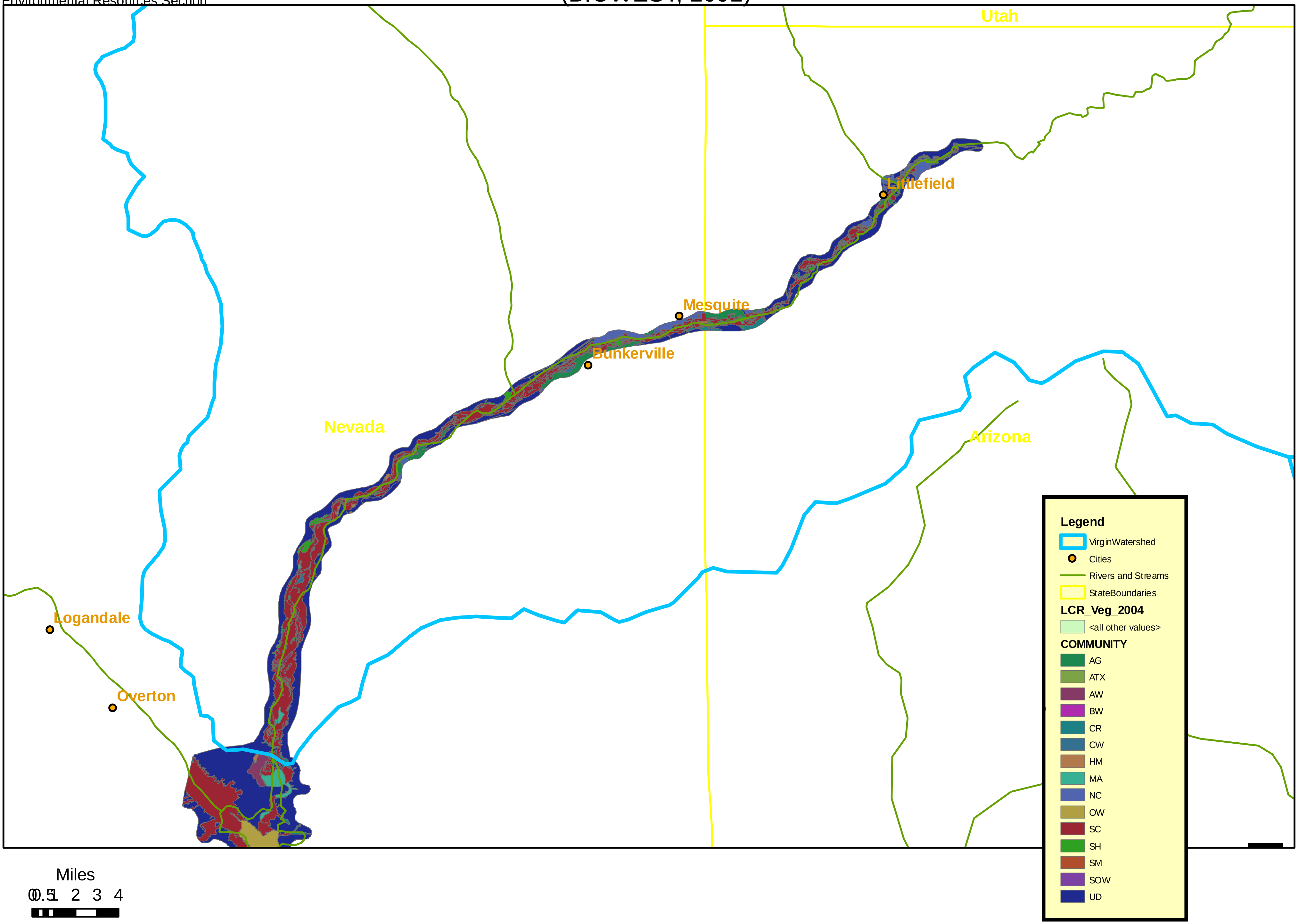
Figure 5.
Vegetation Types in NV and AZ (BIOWEST, 2001)

January 18, 2008



IV. **Lessons Learned**

A. Types of treatment being implemented in the watershed

Definitions

- Fuel reduction: Thinning out of dead and down material.
- Thinning: Selectively removing non-native vegetation in order to reduce the population.
- Treated/Treatment: A treatment is a method to be implemented at a site as described in the applicable specification (i.e.: manual treatment, mechanical treatment, herbicide treatment).
- Herbicide treatment: Application of herbicide to a cut stump (usually greater than 4-6 inches in diameter),whip (less than 4-6 inches in diameter), basal bark, or aerial application with a specific herbicide, usually one of the following. Note: the following information is just a summary of each chemical and details of each is found on the herbicide label. The herbicide label and Material Safety Data Sheets (MSDS) for each chemical should always be read and followed.
    - Triclopyr (Garlon®) contains one or more inert ingredients. The contents of two triclopyr formulations are: Garlon® 3A: triclopyr (44.4%), and inert ingredients (55.6%) including water, emulsifiers, surfactants, and ethanol (1%); and Garlon® 4: triclopyr (61.6%), and inert ingredients (38.4%) including kerosene. Garlon 3A is aquatically approved and Garlon 4 is not as it will break down in water. Garlon 4 can be toxic to many fish species. Triclopyr acts by disturbing plant growth. It is absorbed by green bark, leaves and roots and moves throughout the plant. Triclopyr accumulates in the meristem (growth region) of the plant. Triclopyr should be applied only when there is little or no hazard of spray drift. Triclopyr is active in the soil, and is absorbed by plant roots. Microorganisms degrade triclopyr rapidly; the average half-life in soil is 46 days. Triclopyr degrades more rapidly under warm, moist conditions. Application should not occur in conditions > 90 degrees F. Triclopyr is selective to broadleaf and woody species (including native species).
    - Imazapyr (Arsenal® or Habitat) is a broad-spectrum, nonselective herbicide. This herbicide inhibits the aromatic amino acid biosynthesis pathway and inhibits resprouting by saltcedar. Arsenal® in a 28.7% active ingredient formulation is absorbed by roots and foliage of plants and inhibits plant growth by affecting the biosynthetic pathway of aliphatic amino acids (BASF, 2003). Inert ingredients (such as a nonionic surfactant) are applied at a rate of 71.3% (combined with the 28.7% Imazapyr to equal Arsenal®). Arsenal® has been approved by the Environmental Protection Agency (EPA) for application at least 500 feet away from the active water. Applications should occur in early September when herbicides would be quickly transported to meristem tissues and with carbohydrates via phloem tissues to the root system for storage. Herbicide application during this time period would inhibit root resprouting. Milder weather and higher relative humidity encountered during this period also reduces the thickness of saltcedar leaf cuticles allowing easier herbicide penetration. Habitat (BASF) is an aquatically approved label of Imazapyr and is labeled for wetland and riverine applications.

Per discussions with USFS personnel (Parker, personal communication) who helped develop Garlon®, the pros and cons of each are as follows:

Garlon®	Arsenal®/Habitat
Works well in winter	Works better outside of cold weather
Selective on broadleaf and woody plants (native and non-native)/depends on how applied	Affects all vegetation/ depends how applied
Doesn't move as rapidly into the soil	Does move into the soil/ Soil Residual
Less expensive	More expensive
Public needs to stay out of the area for 48 hours	Public needs to stay out of the area 12 hours
Breaks down in water Garlon 3A is aquatically approved	Must be at least 500 feet away from water to use/Habitat has no restrictions and can legally be applied directly to surface water
Garlon 4 will volatize and cause non target plant mortality from about 80 degrees F. It will transition into the gas form off of the stumps and tree stems and will form a cloud of herbicide fumes that will kill most plants with hundreds of feet of the treated trees. Garlon 4 should not be applied by any method of application during the summer months or generally from April to October in this climate.	Habitat or Garlon 3A is a non volatile alternative during hot weather applications

- Manual treatment: Treatment without the use of heavy machinery – mainly using chainsaws.
- Mechanical treatment: Cutting equipment such as a brush cutter, excavator, brush hog, mulching tractor, bulldozer, rootplow or other appropriate equipment.
  - Cut-stump – Removal of the trunk of the tree using a piece of equipment (i.e.: brush cutter) or by hand using a chainsaw and leaving a stump in place. It is common to then apply herbicide to the remaining stump.
  - Chipping – Processing of material (stumps, limbs, tree trunks) by chipping/cutting into smaller pieces (no more than 3 inches in diameter and any single piece may not exceed 6 inches in length) using a chipper or other machinery.
  - Root plowing – The removal of underground (root crowns) portions of the plant using heavy equipment.
  - Root raking – Raking of the root portions into a pile for removal from site and/or burning on site.
  - Mastication – Processing of material (stumps, limbs, tree trunks) into small pieces (chips) through the use of large equipment (such as a mulching tractor with a rotating head).

- Mowing – Cutting of small resprouts (usually less than 4 inches in diameter) with the use of a large mower or other equipment to effectively ‘mow’ the material. Repeated mowing can cause reduced vigor of resprouts.
- Low Volume Basal Spray (Max Williamson and Doug Parker tech ref): Apply 20% Garlon 4 and vegetable basal oil to basal stems of trees without any cutting. This is the most effective and efficient method for trees up to 6inches in diameter at base. It is also an excellent method to apply to tamarisk resprouts after fire, mastication and other mechanical methods
- Foliar: Apply herbicide (usually 1% Habitat) directly to the foliage of tamarisk canopy.

- Biological Control: Leaf beetle commonly used throughout the west to control tamarisk. The beetle defoliates tamarisk by feeding on the tree. Likely the best long term treatment of tamarisk and least costly.

Utah

For the work that the City of St. George has completed along the Virgin River within the city limits they have use mainly cut-stump treatments and herbicide is applied right away (R. Halverson, pers.comm.). The material is then chipped and spread out on site. Treated stumps are identified and geo-referenced using a Pathfinder GPS system. This work is also discussed in the LVRFFP. After the 2005 flood, tamarisk was removed from along the 115 Bridge down to a mile south of Man O War Bridge using bulldozers (SWCA, 2005).

Washington City also began removal efforts near the 300E Bridge/Washington Fields area after the 2005 flood (SWCA, 2005).

The National Park Service has used various methods: primarily cut stump and low volume basal spray, for their work in the Zion National Park.

Nevada

The BLM, sometimes working with the NPS crews, have used mechanical removal as their method for removing saltcedar. Specific methods include clearing of burned areas with a dozer, piling the material and burning it. Other methods include root plowing and root raking, disking, mastication, and mowing with a Hydro-ax. The BLM have used mechanical removal as their method for removing mature saltcedar. Specific methods include clearing of project areas with a dozer , rotary cutter, or root plow. Debris is then gathered with machinery into piles for burning to reduce the fuel load and potential fire threat. Mowing was employed when necessary to reduce whips heights, making herbicide applications more effective. Herbicide is applied to re-sprouting saltcedar using backpack sprayers to perform basal bark applications of Triclopyr, or foliar application of Imazapyr. Herbicide is applied at all treatments using backpack sprayers by performing basal bark application of Triclopyr or foliar application of Imazapyr. Hand crews are used limitedly as needed. There is an interest in herbicide application by helicopter and/or the use of biocontrol (utilizing the arthropod *Diorhabda elongata* or similar) where feasible.

An overview of removal options is provided in Table 1 below. A good discussion of alternative technologies (as well as tools for revegetation efforts) is included in a document prepared by the Tamarisk Coalition, Riparian Restoration: Assessment of Alternative Technologies for Tamarisk Control, Biomass Reduction and Revegetation (2008) and is included in Appendix B.

Table 1. TAMARISK REMOVAL OPTIONS

Note: These estimated costs are site specific and locations and the information source are provided under each.

Method	**Information Source**	**Cost per acre**	**Pros/Cons**	**% Success/Kill**	**Follow On Treatment**	**Follow On Treatment Cost per acre**
A. Mechanical removal						
A1. Cut-stump using timber axe	R. Halverson, City of St. George, UT	$	Immediate removal of all material, spraying stump directly/ Have to spray resprouts	80 % initial kill	Treatment of resprouts	$
A2. Mechanical removal with basal bark spraying	T. Rash, BLM, NV			1-30% initial kill	Spraying of resprouts using backpack sprayer: Basal bark Foliar	
A3. Treatment of material: Pile burning Root plowing Disking						
B. Hand removal (chainsaws and crews) – cut/stump treatment	T. Rash, BLM, NV; C. Deuser, NPS		Less soil degradation/ Slow and more expensive, still having to spray resprouts	75-90% mortality		~$1,000/acre, depending on access & density

C. Natural removal (i.e.: goats, beetles)			Natural method that doesn't utilize chemicals/Slow for large trees. Beetles are long term, ignore boundaries and can treat remote and difficult to access areas. Beetles are also selective and non-ground disturbing.	Still unknown at this time but may take 3-4 defoliations prior to killing trees		
D. Aerial spraying	North Star	$200	Fast & effective/ Herbicide use, standing dead for 18 months, still have to mechanically remove, don't have to mechanically remove standing, dead trees can be left on site to biodegrade, reduce soil erosion and provide vertical mulch and microsites for natural plant recovery.			
E. Low Volume Basal Spray			Quicker and cheaper than cut stump, no ground disturbance, very effective 90-99% mortality, more costly than aerial or foliar			

			treatment, but also more selective. 20% Garlon 4/80% JLB basal oil – cannot be applied during hot temps due to volatization.			

B. Success of treatments

Utah

At the locations being treated in and around the City of St. George, resprouts are treated in the spring. An initial kill percentage of 80% was found on their sites.

Annual maintenance and follow-up is occurring by treating resprouts of saltcedar by the NPS in the Zion National Park. Initial treatments have shown approximately 85-100% control. Most sites take minimal effort to maintain after initial treatment. It is probably best not to manage tamarisk within the annual floodplain since most tamarisk recruitment occurs here but does not establish in the long term (C. Deuser, pers. comm..).

Nevada

BLM also performs annual maintenance of resprouts by applying chemical to whips and new seedlings using backpack sprayers. An initial kill of treatment areas ranged from 1-30%. It was variable due to site specifics such as burned or non-burned sites, depth to groundwater, type of equipment, salt crusting and the season of treatment.

C. Restoration efforts to date

Utah

At the City of St. George project sites, portions of the Santa Clara River have been replanted with willow (*Salix* spp.) and cottonwood (*Populus* spp.) appears to be coming back on its own.

Most sites still have native species intermixed on site so propagules are available to colonize the site. Some areas on the river within Zion Canyon have converted to exotic winter annual brome grasses such as cheatgrass, rip-gut brome and Russian thistle on sandy sites along the river terrace. Research and control actions have been implemented to manage these sites. Some native trees have been transplanted on the upper terrace sites with minimal success. Plenty of cottonwood trees exist in the floodplain and will likely need a late spring flood to stimulate germination and recruitment.

Nevada

At the Nevada projects a fair amount of restoration has taken place. Seeding has occurred within in all of the areas that were treated mechanically by using a hand crew and ATV to perform the seeding. Seed species include: Quailbush (*Atriplex lentiformis*) and Desert saltbush (*Atriplex polycarpa*). In 2008, additional species will be added such as four wing saltbush (*Atriplex canescens*). Native recruitment on many of the treatment acres has now reached a very favorable trajectory (including. cottonwood, willow, wolfberry (*Lycium* spp.), arrowweed (*Pluchea sericea*); iodine bush; inland salt grass; heliotrope; baccharis (*Baccharis salicifolia*); honey mesquite; screwbean mesquite (*Prosopis pubescens*); catclaw acacia; rushes; sedges; catclaw; and various forbs). A 30-acre tree planting and drip irrigation array of honey and screwbean mesquite (over 1000 trees) was installed, though most of this was destroyed by the 2004-2005 floods.

D. Lessons learned

Many lessons learned and shared successes are described in the sections above but a few lessons or ideas to explore were shared by partners from the watershed as follows:

- Current research is being conducted on the Virgin River in NV to determine effectiveness of tamarisk treatments and evaluate various revegetation techniques led by Tom Dudley (UCSB) and Matt Brooks (USGS) on BLM and NPS lands in the drainage. The study will include simulation of biocontrol by herbicide induced defoliation and basal spray methods in monotypic tamarisk and mixed native stands. Also monitoring will occur on BLM larger scale mechanical and chemical treatment sites to determine secondary invasion plant response to treatments. Various active revegetation techniques will be assessed evaluating effectiveness o using rooted materials, cuttings and seeding of native species. Being cautious about planting and investing in rooted plant material and elaborate irrigation systems may be needed, since many sites will be subject to flooding.
- The continuous supply of river borne salt cedar seed highlights the importance of entire watershed participation, including state, city, and private landowners, and the importance of working from the headwaters down.

V. **Technical considerations**

A. Tools that are lacking

Each agency working on the watershed has mentioned tools that they are currently lacking that would aid in saltcedar removal and restoration. These include aerial application of herbicide, use of biocontrol, need for monitoring equipment and public outreach. Each of these items and their potential is described further below.

Aerial application of herbicide

Large scale herbicide saltcedar control includes aerial application of various amounts (depending on the type) of herbicide based on the size of the patch of saltcedar and the label directions. Applications can be made via fixed wing airplane or helicopter. It is best used over large acreages and where there exists a monotypic stand of saltcedar with little to no native vegetation. This method has been used with varying levels of success. It allows the quick treatment of a large area at one time at a fairly low cost, but the sprayed material must remain standing in place for 24-36 months to allow the chemical to move through the whole tree. After this period of time, the material may still need to be processed in some way in order to begin restoration, though not in all instances. In some cases, dead trees can be left on site to biodegrade, reducing soil erosion and provide vertical mulch and microsites for natural plant recovery, temporary bird perching and other wildlife benefits. The removal of the standing dead may not be necessary in remote areas. If it is possible/practical to remove all standing dead, then it may be more efficient to treat the area with extraction of whole live trees rather than use aerial herbicide application.

Current tools to address saltcedar in the watershed are already varied but saltcedar control strategies must be flexible to produce desired results (Taylor and McDaniel 1998). It is always wise to have as many tools as possible in the toolbox to choose from. Aerial herbicide application is another tool to choose from.

Biocontrol

The biological control program for saltcedar has led to open releases of a specialist beetle (Chrysmelidae: *Diorhabda elongata*) in several locations (Dudley and Kazmer, 2005). Research sites currently exist in more than 10 western states including: CO, WY, UT, NV, and CA. Sites were initially treated and used as research sites beginning in 1999 (DeLoach et al., n.d.). Since that time, other sites throughout the west have been added to test the use of *Diorhabda* to reduce saltcedar populations. The use of *D. elongata* appears to be less efficient south of the 38-39th parallel (which is just south of St. George, UT) due to an earlier shift to warmer weather. Other species that might work north of the 38-39th parallel are being investigated.

D. elongata seems to damage saltcedar foliage by scraping tissue off the leaves rather than removing sections of the leaf. This causes sections of twigs beyond the damage to turn yellow and eventually dry up and fall off. *D. elongata* can, therefore, cause the death of more plant tissue than it actually consumes (http://www.ars.usda.gov/Research/docs.htm?docid=6937#damage).

Saltcedar has a great capacity to re-sprout after damage from factors such as cutting and burning. It can also re-sprout after complete defoliation by insects. Further detailed studies will be necessary to discern the beetle densities and number of years of defoliation necessary to kill saltcedar plants of different age and size. Three to four years of stress can lead to mortality.

As discussed above, a population of beetles was also released in the St. George, Utah area in 2006. These trees are now showing signs of stress (C. Cram, pers. comm.). The University of Nevada is assisting with monitoring and shows that the beetle has moved downstream to Beaver Dam Wash. The beetles, unfortunately, do no attack *T. parviflora* (T. Dudley, pers. comm.).

Again, this is another tool that could be used as part of the Tamarisk Toolbox when addressing saltcedar. Many times, more than one tool is necessary and different tools may be used at different phases of a project. For example, aerial herbicide could be used as an initial treatment against saltcedar and biocontrol (be it *Diorhabda*, goats or other agents) can be good tool for follow-up maintenance treatment of resprouts. Whichever tool(s) is used, it is best to consider the goals of the project before deciding upon what might prove to be the most successful.

Another tool to consider might be combining biocontrol with other treatments or using biocontrol as a follow-up treatment for maintenance. Again, all of the tools discussed can be utilized in partnership with others or new tools as they evolve.

Monitoring

Monitoring, and adaptive management, can help aid the discovery of what tools are most successful at which projects. The only way to determine if your project has been successful is to monitoring the site BEFORE, DURING, and AFTER the work has been completed. This can also aid in determining the level of maintenance or change in treatments (adaptive management) that may be warranted. An effective monitoring program addresses clear questions, uses consistent and accepted methods to produce high-quality data, and includes provisions for management (Lovett et al., 2007). The biggest roadblock to implementing and maintaining a monitoring program is usually funding and staffing. But, the cost of having to redo projects without the knowledge of what has been done before and how it worked can cost more in the long run. A coordinated watershed monitoring effort for the Virgin River Watershed is recommended to allow all managers and users of the watershed to be able to share data that will aid in reducing costs in the overall long-term restoration of areas infested with saltcedar.

Restoration Techniques and Planning

It was noted by the Virgin River Watershed stakeholders that more information is needed regarding tools for restoration. Restoration should be a well thought out component of a salt cedar treatment project and should discuss issues such as weed control, soil salinity, species to be considered for revegetation efforts, etc. These components and many others should be considered and are very site specific when planning for long-term restoration success.

Public Outreach

Public outreach and education is very important to the cause of saltcedar removal projects. A public involvement plan should be developed an implemented within the watershed to educate the public in invasive species, natural ecosystem, and elicit participation in control, monitoring and prevention.

VI. <u>Policy/Regulatory Considerations</u>

A. General requirements

In order to treat, remove or manage tamarisk in any way, some form of environmental compliance is usually required. This is usually in the form of an Environmental Assessment (EA). The level of detail and documentation required depends on the agency performing the action and what the land ownership is. If there is any kind of federal nexus (the action is being performed by a federal agency, the land is federally owned, and/or funds expended are provided by the federal government), then the National Environmental Policy Act (NEPA) must be followed when developing an EA (or Environmental Impact Statement if one is required). If there is any potential threat to threatened or endangered species, Section 7 consultation with the U.S. Fish and Wildlife Service (USFWS) is also required and the development of a Biological Assessment (BA) may also be required. Non-federal agencies are also required to consult with the USFWS under Section 10 of the Endangered Species Act (ESA). Specific species of interest in the Virgin River Watershed should be evaluated on a case by case basis.

B. Specific required permitting (depending upon situation)

1. Herbicide application

Herbicides should be applied by a State Certified Herbicide Applicator, as applicable, in accordance with Environmental Protection Agency (EPA) label restrictions and recommendations. The following rules should be incorporated into any specifications to be followed by the agency or implemented by a contractor:

- The Certified Applicator must wear clothing and personal protective equipment as specified on the herbicide label.
- Prior to application of herbicide, all equipment should be inspected for leaks, clogging, wear, or damage and should be repaired prior to being used.
- For application of Arsenal®, the herbicide must not be applied within one (1) mile upstream or 500 feet downstream of drinking water intakes or irrigation water intakes currently in use. Before treating adjacent to any public water bodies, contact the controlling water authority (EPA, 2001).

Supplemental labeling may also exist by County depending upon the herbicide to be used. Applicators should coordinate with their local Department of Agriculture or Pesticide Management Bureau for further guidance.

2. Other regulations/permitting

Specific items that would need to be addressed in most salt cedar treatment efforts include coordination in regard to the Endangered Species Act (species of interest include but are not limited to the Southwestern Willow Flycatcher and the Yuma clapper rail), and Section 404 of the Clean Water Act. Other federal, state and/or local regulations may apply depending on the location.

C. Programmatic Environmental Assessment

There is a desire for a Programmatic Environmental Assessment (PEA) for work on tamarisk throughout the entire watershed. This could be accomplished but would require a great amount of coordination between the agencies in the watershed and the designation of a lead agency (or possibly two agencies) to write the document. There is a great amount of existing information for certain portions of the watershed, but there is also still information lacking for the more remote geographic areas of the watershed. In reference to tamarisk, however, the problem is fairly clear and the potential impacts extreme as described above. It would take the desire of a coordinated watershed team with a lead agency(s) to move this option forward. This is also a task that will be recommended to pursue at the end of this document.

VII. Recommendations

Although there are numerous activities underway within the watershed, a comprehensive plan for invasive species management should be developed for the watershed. Such a plan would contribute to invasive species management in the watershed and must include a restoration component to be effective. Land management and resource agencies currently conducting invasive species work should be involved and could lead this effort. Potential partners include: Bureau of Land Management, National Park Service, US Fish and Wildlife Service, Natural Resource Conservation Service, U.S. Army Corps of Engineers, State agencies, local governments and NGO's such as The Nature Conservancy, Partners in Conservation, or Tamarisk Coalition.

A. Vegetation classification throughout watershed

Though much has been done (as discussed in this document), there appears to be a need for an overall concise mapping effort (utilizing existing aerial photography and/or vegetation mapping as much as possible) to provide precise information on location and acreages of existing salt cedar within the watershed. A similar effort has been performed by the Tamarisk Coalition for the Southeastern Utah Tamarisk Partnership (SEUTP) (Tamarisk Coalition, 2008).

B. Prioritization of areas

The prioritization of work areas throughout the watershed has somewhat been set within larger urban communities in each state but not including all portions of the watershed within each state. These priorities have currently been set dependent upon issues related to natural disasters as discussed in previous sections. These priorities are being set in response to these disasters but priorities should be set to help prevent these disasters. Prioritization throughout the watershed could be further defined based on many factors and could also direct the overall restoration of the watershed and its needs. An example matrix with some of the potential factors that could be weighted to help determine priorities by communities (and potential breakdown of geographic areas to help make them more workable) are provided in Table 2 below. Other factors could be added as seen to contribute to threat to the watershed in relation to tamarisk. An example of a similar effort exists in the SEUTP mentioned above.

C. Implementation

Once priority areas are identified and agreed to, finding funds to implement the work should be undertaken. Throughout the processes described in A and B above this may already have been considered, especially by the management agencies. Many times funding has to be applied for or requested 1 to 2 years in advance so this step should be considered with that in mind. There are many funding opportunities available for addressing tamarisk issues and The Tamarisk Coalition has done a good job of condensing this information into one document which is provided in Appendix A of this document.

Table 2. PRIORITIZATION OF TAMARISK TREATMENT LOCATIONS – EXAMPLE MATRIX

Location (Reach/Sub-reach)	Percent/acres tamarisk present	Flooding threat	Fire threat	Water quantity	Soil salinity	Water quality	Wildlife Value	Other	Overall Score
UT									
Headwaters through East Fork									
East Fork to North Fork									
North Fork to North Creek									
North Creek through St. George									
W boundary of St. George to State Line									
Previously treated areas									
AZ (UT state line to NV state line)									
Previously treated areas									
NV (State line to Park boundary)									
Previously treated areas									

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Appendix A

Grant Opportunities Available for Addressing Tamarisk Issues

The following tables list possible grant opportunities available for addressing tamarisk issues and riparian restoration. The tables are divided into Non-profit Foundations, Corporate, and Other Funding Sources; Federal Grants; and Congress Chartered Foundations. State directed funding sources will be added at a later date.

This list of grant opportunities has been compiled as a tool to be used as a starting point for the reader's grant funding research. This list is not exhaustive and is designed only to provide an overview of available grants. For more detailed information, the reader is encouraged to utilize the resources listed below, visit the funding sources website, or contact the funding source directly.

- ✓ Environmental Grantmaking Foundations www.environmentalgrants.com
- ✓ Center for Invasive Plant Management www.weedcenter.org
- ✓ Federal Government www.grants.gov

The activities funded by the grantors have been identified as Advocacy, Education, Policy, Direct Action, Research, and Start Up. The following categories are defined to aid the reader in selecting appropriate grants. Individual grantors may define categories somewhat differently.

Advocacy (Adv) includes activities associated with communicating about tamarisk issues such as organizing community meetings or distributing public education materials.

Education (Edu) involves direct education programs to a targeted group.

Policy (Pol) is defined as activities related to influencing and/or developing environmental policies.

Direct Action (Dir) includes activities such as volunteerism, control, revegetation, and other direct implementations.

Research (Res) is defined as planning and implementing basic scientific research.

Start Up (SU) is defined as funds for a new project ("seed money") or funds for a new organization.

Additionally, geography is included to indicate the physical locations the grantor emphasizes.

Grant information is current as of June 2007. Financial information is generally from 2004 or 2005. Blank spaces indicate that no information was available. **Grants and grantors are subject to change at anytime for a variety of reasons. It is critical that the funding sources are contacted for the most current information before any type of submission.**

Non profit Foundations, Corporate, and Other Funding Sources

Organization	Website	Geography	Award Range	Median Grant	Grants/yr	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
444S Foundation		ID, MT, WA	$5,000 to $210,000	$20,000	30	✔	✔	✔	✔	☐	☐
Abelard Foundation West	www.commoncounsel.org	US	$9,000 to $12,000	$10,000	5	✔	☐	☐	✔	☐	☐
Acorn Foundation	http://www.commoncounsel.org	Western US	$5,000 to $10,000	$8,000	15	✔	✔	☐	✔	☐	☐
Afognak Foundation		ID, WY	$10,000 to $100,000	$75,000	8	☐	☐	☐	✔	☐	☐
Aksel Nielson Foundation		CO	$100 to $15,000	$5,500	4	☐	✔	☐	✔	☐	☐
Altria	www.altria.com	Altria plant locations	$2,500 to $50,000	$25,000		✔	☐	☐	✔	☐	☐
American Forests	www.americanforests.org	US				☐	☐	☐	✔	☐	☐
American Honda Foundation	http://corporate.honda.com/america/philanthropy.aspx	US	$20,000 to $87,000	$40,000	5	☐	✔	☐	☐	☐	☐
American Landscape and Nursery Association	http://www.anla.org/research/growing_effectiveness.htm	US	$5,000 to $25,000			☐	☐	☐	☐	✔	☐
Angelica Foundation	www.angelicafoundation.org	CA, NM, Mexico	$300 to $30,000	$7,500	8	✔	✔	✔	✔	✔	✔
Animas Foundation		NM	$1,000 to $1,500	$1,250	2	☐	☐	☐	✔	☐	☐
Anna Keesling Ackerman Fund	www.elpomar.org	CO, El Paso County				☐	☐	☐	☐	☐	☐
APS Foundation, Inc.	http://www.aps.com/general_info/aboutaps_14.html	AZ				☐	✔	☐	✔	☐	☐

Organization	Website	Geography	Award Range	Median Grant	Grants/yr	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
Argosy Foundation	www.argosyfnd.org	US				☐	✔	☐	☐	✔	☐
As You Sow	http://asyousow.org/	CA	$5,000-$10,000	$10,000	15	✔	✔	✔	✔	✔	☐
Aspen Business Center		CO, Aspen	$3,000 to $13,000			☐	✔	☐	☐	☐	☐
Aurora Foundation		NM	$250 to $35,000	$7,800	6	☐	✔	☐	☐	☐	☐
Bacon Family Foundation		CO	$4,000 to $10,000		50	☐	☐	☐	☐	☐	☐
Barbara Smith Fund	www.jaf.org	US	$1,000 to $10,000			☐	☐	☐	☐	☐	☐
BASF Professional Vegetation Management Invasive Vegetation Management Matching Grant	http://www.vmanswers.com/content.aspx?mid=0&pid=1406	US	to $30,000 as non-federal matchi			☐	☐	☐	✔	✔	☐
Ben and Jerry's Foundation	www.benjerry.com/foundation	US	$1,001 - $15,000	$10,000	56	☐	☐	✔	✔	☐	☐
Beneficia	www.beneficiafoundation.org	US	,000. In most instances, grants are	$23,500	22	✔	☐	✔	☐	☐	☐
BF Foundation		NM, CO	$500 to $7,500	$1,000	10	✔	✔	☐	☐	☐	☐
Bonneville Environmental Foundation	www.b-e-f.org	ID, MT, OR, WA				☐	✔	☐	✔	✔	☐
Bradshaw Knight Foundation	www.bkfnd.org	CO, Delta County	$30 to $30,000	$10,000	15	☐	✔	✔	☐	✔	☐
Brainerd Foundation	www.brainerd.org	ID, WA ,OR, MT				✔	✔	✔	✔	✔	✔
Brindle Foundation		NM	$2,500 to $30,000	$17,500	4	☐	✔	☐	☐	☐	☐

Organization	Website	Geography	Award Range	Median Grant	Grants/yr	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
Bullitt Foundation	www.bullitt.org	ID, MT, OR, WA	$5,000 to $120,000	$25,000	143	☑	☐	☐	☑	☐	☐
Burning Foundation	http://foundationcenter.org/grantmaker/burning/interest.html	WA, OR	$5,000 to $12,000	$10,000		☐	☐	☐	☑	☐	☐
Bydale Foundation		US	$2,500 to $25,000	$5,000	9	☑	☑	☐	☑	☐	☑
Caleb C. and Julia W. Dula Educational Charitable Foundation		US	$5,000 to $50,000	$7,500	8	☐	☑	☐	☑	☐	☐
Captain Planet Foundation	www.captainplanetfdn.org	US	$250 to $2,500			☐	☑	☐	☑	☐	☐
Cedar Tree Foundation	cedartreefound.org	US	$5,000 to $200,000			☐	☑	☑	☐	☐	☐
Center for Invasive Plant Management	www.weedcenter.org					☐	☐	☐	☐	☐	☐
Charles De Vlieg Foundation		ID, WA	$2,000 to $95,000	$9,100	5	☑	☑	☐	☑	☑	☐
Charles Delmar Foundation		US	$250 to $3,000	$1,000	12	☑	☐	☐	☑	☐	☐
Charles Stewart Mott	www.mott.org	US	$100,000 to $500,000			☑	☑	☑	☐	☐	☐
Charlotte Martin Foundation.	www.charlottemartin.org	WA, OR, MT, ID	$1,000 to $100,000			☑	☑	☐	☑	☐	☐
Cheeryble Foundation		US	$900 to $50,000	$1,800	7	☑	☐	☐	☑	☐	☐
Christensen Fund	www.christensenfund.org	S.W. US	$50,000 to $200,000			☑	☑	☐	☑	☐	☐
Cinnabar Foundation		WY, MT	$1,000 to $9,000	$5,000	55	☑	☑	☐	☑	☐	☐

Organization	Website	Geography	Award Range	Median Grant	Grants/yr	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
Clark Charitable Trust		US	$1,000 to $15,000	$4,000	5	☐	☑	☐	☑	☐	☐
Collins Foundation	www.collinsfoundation.org	OR	$33,445			☑	☑	☐	☐	☑	☐
Compton Foundation	www.comptonfoundation.org	Pacific Coast	$10,000 to $190,000	$20,000	81	☑	☑	☑	☑	☑	☐
Conservation and Research Foundation		US	$100 to $3,000	$1,000	10	☑	☑	☑	☑	☑	☐
Conservation Trust Grants from National Geographic Society	www.nationalgeographic.com/research/grant/rg2.html		$15,000 to $20,000			☐	☑	☐	☑	☑	☐
Cooper Foundation		NE	$2,000 to $30,000			☐	☐	☑	☑	☐	☐
David and Lucille Packard Foundation	www.packard.org	CO, Pueblo	Max $50,000			☑	☑	☐	☑	☐	☐
Dean Witter Foundation	www.deanwitterfoundation.org	CA, Northern	$5,000 to $25,000	$10,000	17	☐	☑	☐	☑	☑	☐
Donnell Initiative Fund		CO	$10,000 to $20,000		7	☐	☐	☐	☐	☐	☐
Dudley Foundation	www.dudleyfoundation.org	MT, OR, WA	$2,000 to $9,100	$4,000	13	☐	☑	☐	☑	☐	☐
Eddy Foundation		US	$150 to $10,000	$500	9	☑	☐	☐	☑	☐	☐
Education Foundation of America	www.efaw.org	US	$30,000 to $160,000			☑	☑	☑	☑	☐	☑
El Pomar Foundation	www.elpomar.org	CO	$2,500 to $10,000	$10,000	9	☐	☑	☐	☑	☐	☐
Elinor Patterson Baker Foundation		US	$2,000 to $75,000	$10,000	23	☐	☐	☐	☑	☑	☐

Organization	Website	Geography	Award Range	Median Grant	Grants/yr	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
Elkind Family Foundation		CA	$100 to $1,000	$250	31	☐	☐	☐	☑	☐	☐
Environmental Systems Research Institute (ESRI) Conservation Technology Support Program	http://www.conservationgis.org/aagisgrant.html	US				☐	☑	☐	☐	☐	☐
Environmental Trust		CO	$5,000 to $27,000		12	☑	☑	☑	☐	☑	☐
ESRI Conservation Program	http://www.conservationgis.org/aaesrigrants.html	US				☐	☑	☐	☐	☐	☐
ESRI Grant Assistance Program	http://www.esri.com/grants/	US				☐	☑	☐	☑	☐	☐
Fairfax Foundation		US	$1,000 to $75,000	$38,000	2	☐	☐	☐	☑	☐	☐
Firman Fund		CO	$1,000 to $15,000	$8,750	4	☑	☑	☐	☑	☐	☐
FishAmerica Foundation	www.asafishing.org/faf	US	$7,500.			☑	☐	☐	☑	☐	☐
Fledgling Fund		Pacific Flyway	$10,000 to $34,000			☐	☑	☑	☑	☑	☐
Ford Foundations	http://www.fordfound.org/	US				☑	☐	☑	☐	☑	☐
Ford Motor Company Fund	www.ford.com	US	$600 to $1,200,000	$10,000	25	☐	☑	☑	☐	☑	☐
Fund for Wild Nature	www.fundwildnature.org	US	$1,000 to $3,000			☑	☐	☐	☑	☐	☐
Gates Foundation	http://www.gatesfamilyfoundation.org/	CO	$20,000 to $220,000	$37,500	12	☑	☐	☐	☑	☐	☐
Gibbet Hill Foundation		US	$10,000 to $122,500	$66,250	2	☐	☑	☐	☐	☐	☐

Organization	Website	Geography	Award Range	Median Grant	Grants/yr	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
Harder Foundation	www.harderfoundation.org	CO, ID, MT, NV, OR, UT, WA, WY	$1,000 and $35,000			☑	☐	☐	☑	☐	☐
Harris and Frances Block Foundation	www.blockfound.org	US	Small grants			☐	☑	☐	☑	☐	☐
Hawley Family Foundation		US	$2,000 to $50,000	$10,000	23	☑	☑	☐	☑	☐	☐
Helen K. and Arthur E. Johnson Foundation	http://www.johnsonfoundation.org/	CO	$25,000 to $100,000	$50,000	3	☐	☑	☐	☑	☐	☐
Hugh and Jane Ferguson Foundation	www.fdncenter.org/grantmaker/ferguson	ID, MT, OR, WA	$1,500 to $7,500 typical			☑	☑	☐	☐	☐	☐
Intermountain West Joint Venture Project	http://iwjv.org/	Intermountain West	Max $100,000			☐	☐	☐	☑	☑	☑
J.M. Kaplan Fund, Inc.	www.jmkfund.org	Border regions	$75 to $220,000			☐	☐	☐	☑	☐	☐
Jacob and Terese Hershey Foundation		CO, TX				☑	☑	☑	☑	☑	☐
James M. Cox Foundation		Areas in which Cox Enterprises	$20,000 to $200,000	$4,500	4	☐	☑	☐	☑	☐	☐
James M. Cox Jr. Foundation		Areas in which Cox Enterprises	$20,000 t0 $45,000	$35,000	2	☐	☑	☐	☑	☐	☐
Jenifer Altman Foundation	http://jaf.org/apply/index.html	US	$1,000 to $10,000	$2,750	20	☑	☑	☑	☑	☑	☑
Justine & Leslie Bialy Charitable Trust		Pre-selected in CO	$12,500 to $17,538	$16,000	4	☐	☐	☐	☑	☐	☐
Katz Family		US	$1,000 to $28,000	$10,000	7	☐	☑	☐	☑	☐	☐
Kongsgaard-Goldman Foundation	http://www.kongsgaard-goldman.org	WA, ID, MT, OR	$1,000 to $15,000			☐	☐	☐	☐	☐	☐

Organization	Website	Geography	Award Range	Median Grant	Grants/yr	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
Laird Norton Foundation	http://www.lairdnorton.org/index.htm	ID, MT,OR, and WA	$10,000 Range	$10,000		☑	☑	☐	☐	☑	☐
Lawrence Foundation	http://thelawrencefoundation.org					☐	☐	☐	☑	☐	☐
Liz Claiborne and Art Ortenberg Foundation	www.lcaof.org	Northern Rocky Mountain Region	$50,000 to $200,000			☑	☑	☐	☑	☑	☐
Maki Foundation		Rocky Mountain Region	$3,000to $10,000	$4,200	57	☑	☑	☐	☐	☐	☐
Manitou Foundation		San Luis Valley, CO	$5,000 to $245,000	$25,000	3	☐	☐	☐	☑	☑	☐
Max and Anna Levinson Foundation	www.levinsonfoundation.org	Southwestern US	$2,500 to $5,000	$3,700	2	☑	☐	☑	☐	☑	☐
McGrath Investment Foundation		CO, OR	$8,500 to $14,000	$11,500	2	☐	☑	☐	☑	☑	☐
Nathan Cummings Foundation	www.nathancummings.org	US				☑	☑	☑	☐	☑	☐
New-Land Foundation		AK, CO Plateau	$5,000 to $30,000			☑	☑	☑	☑	☐	☑
Norcross Wildlife Foundation Inc.	www.norcrossws.org	US	Max $10,000	$5,000		☐	☑	☐	☑	☐	☐
Northwest Fund for the Environment	http://www.nwfund.org/	WA	$1,000 to $40,000.			☑	☑	☑	☑	☑	☐
Patagonia	www.patagonia.com	US	$3,000 to $8,000		376	☑	☐	☐	☑	☐	☐
R.E.I	www.REI.com	US				☐	☑	☐	☑	☐	☐
Ralph L. Smith Foundation		CO, AZ, CA, OR	$1,000 to $62,000	5,000	37	☐	☑	☐	☑	☐	☐

Organization	Website	Geography	Award Range	Median Grant	Grants/yr	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
Rockefeller Family Fund, Inc.	www.rffund.org	US				☑	☐	☑	☐	☐	☐
Rockefeller Philanthropy Advisors	www.rockpa.org	US				☑	☑	☑	☑	☐	☑
Ruth H. Brown Foundation		CO, Western US	$5,000 to $20,000	$4,000	27	☐	☑	☐	☑	☐	☐
Sandler Family Supporting Foundation		US	$20,000 to $500,000	$87,500	16	☐	☐	☐	☑	☐	☐
Shapiro Family Charitable Foundation		US	$250 to $2,500	$1,000	12	☐	☐	☐	☑	☐	☐
Steven C. Leuthold		US	$100 to $40,000	$5,000	32	☑	☑	☐	☑	☐	☐
Surdura Foundation	www.surdna.org		$50,000 to $200,000	$		☑	☑	☑	☑	☐	☐
Tapeats Fund		US	$2,500 to $50,000	$10,000	17	☐	☑	☐	☑	☐	☐
Tides Foundation	www.tidesfoundation.org	US	$7,000 to $10,000		1,192	☐	☐	☐	☐	☐	☐
Towards Sustainability Foundation		US	$2,500 to $50,000	$7,500	10	☑	☑	☐	☑	☐	☐
Town Creek Foundation	www.towncreekfdn.org	US	$5,000 to $75,000	$38,000	58	☑	☐	☑	☑	☐	☐
Tuscany Research Institute		CA	$1,000 to $200,000	$92,000	3	☐	☐	☐	☑	☑	☐
Unity Avenue Foundation	www.srinc.biz	US	$4,000 to $20,000	$10,000	10	☐	☑	☐	☐	☐	☐
Wallace Genetic Foundation	www.wallacegenetic.org	US	$25,000 to $40,000	$30,000	73	☑	☑	☐	☑	☑	☐

Organization	Website	Geography	Award Range	Median Grant	Grants/yr	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
Weeden Foundation	http://www.weedenfdn.org					✔	☐	☐	✔	☐	☐
Western Colorado Community Foundation	http://www.wc-cf.org/	Western CO	$500 and $1,000			☐	✔	☐	✔	✔	☐
Whole Systems Foundation	www.whole-systems.org	US	$500 to $5,000	$2,000	17	✔	✔	☐	☐	✔	☐
Wiegers Family Foundation		CO	$250 to $75,000	$1,000	5	☐	✔	☐	✔	☐	☐
Wilburforce Foundation	www.wilburforce.org	AZ, MT, ID, UT, NM, OR, WA, WY	$10,000 to $650,000	$31,750	156	✔	☐	☐	✔	☐	✔
Wildlife Forever	http://www.wildlifeforever.org/	US	$1,000 to $10,000			☐	✔	☐	✔	✔	☐
Wildlife Habitat Policy Research Program	http://www.whprp.org	US	$50,000 to $190,000			✔	☐	✔	✔	✔	☐
Willard L. Eccles Charitable Foundation, Inc.		UT, CO, MT, ID	$2,500 to $215,000	$2,500	8	✔	☐	☐	✔	☐	☐
William and Flora Hewlett Foundation	www.hewlett.org	Western US	$20,000 - $50,000		1,170	☐	✔	✔	✔	✔	☐
William C. Kenney Watershed Protection Foundation	http://www.kenneyfdn.org/	CO, AZ, CA, MT, NV, NM, OR, UT	$5,000 to $75,000			☐	☐	☐	✔	☐	☐
William E. Weiss Foundation		US	$5,000 to $25,000	$20,000	5	✔	☐	☐	✔	☐	☐
William H. & Mattie Wattis Harris Foundation		US	$1,000 to $10,000	$2,000	19	✔	✔	☐	✔	☐	☐
Winn Foundation Trust		US				✔	✔	☐	✔	✔	☐
Winslow Foundation		US	$250 to $100,000	$10,000	27	✔	✔	✔	☐	✔	✔

Organization	Website	Geography	Award Range	Median Grant	Grants/yr	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
Wyss Foundation	www.wyssfoundation.org	Intermountain West	$1,000 to $300,000	$34,500	44	✓	✓	✓		✓	

Federal Grants

Organization	Website	Funding Name	Geography	Award Range	Adv	Edu	Pol	Dir	Res	SU
Army Corps of Engineers	http://www.aocweb.org/emr/Portals/2/Section%20206%20Restoration%20Grants.pdf	Aquatic Ecosystem Restoration	US	35% local match of total project costs required.	☐	☐	☐	✔	☐	☐
BLM	http://www.grants.gov/search/search.do?oppId=14356&mode=VIEW	Noxious Weed Control on Public Lands in Converse County, Wyoming	WY, Converse County	$3,000	☐	☐	☐	✔	☐	☐
Bureau of Land Management (BLM)	http://www.grants.gov/search/search.do?oppId=12765&mode=VIEW	Noxious Weed Management in Montana, North Dakota, and South Dakota	MT, ND, SD	Max $13,500	☐	☐	☐	✔	☐	☐
Department of Commerce National Oceanic and Atmospheric Administration (NOAA)	http://www.nmfs.noaa.gov/habitat/restoration/projects_programs/crp/partners_funding/callforprojects4.html	Community-based Restoration Project and Regional Partnership Grants	US	$30,000 - $250,000, 1:1 match required	☐	☐	☐	✔	☐	☐
Department of the Interior (DOI)	http://www.grants.gov/search/search.do?mode=VIEW&oppId=12803	Water Conservation Field Services Program	WY	Max $50,000	☐	☐	☐	✔	☐	☐
DOI		Hazardous Fuels Reduction Program	US		☐	☐	☐	✔	☐	☐
DOI		Mitigation of Resources Impacted by Colorado River Storage Project (CRSP)	Colorado River (excluding	$20,000	☐	✔	☐	✔	✔	☐

Organization	Website	Funding Name	Geography	Award Range	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
Environmental Protection Agency (EPA)	http://www.epa.gov/owow/wetlands	Clean Water State Revolving Fund (CWSRF)		Loans can cover 100% of eligible costs. Interest rates between market rate and 0%.	☐	☐	☐	☑	☐	☐
EPA	http://www.epa.gov/owow/wetlands/	Wetland Program Development Grants	US		☐	☐	☐	☑	☑	☐
EPA	www.epa.gov/ow	Surveys, Studies, Investigations, Demonstrations, and Training Grants and Cooperative Agreements of Clean Water Act		$15,000 to $4,970,000	☐	☐	☐	☑	☑	☐
EPA	www.epa.gov	Targeted Watershed Grants	US	Max $900,000, 25% local match of total project costs required.	☐	☐	☐	☑	☐	☐
EPA	http://www.epa.gov/owow/wetlands/restore/5star/index.html	Five Star Restoration Program	US	$5,000 to $20,000	☐	☑	☐	☑	☐	☐
EPA, U.S. Department of Agriculture (USDA)	http://es.epa.gov/ncer/rfa/2007/2007_star_ecoimpacts.html - Synopsis	Ecological Impacts from the Interactions of Climate Change, Land Use Change and Invasive Species: A Joint Research Solicitation	US	Up to $600,000	☐	☐	☐	☑	☐	☐
National Park Service (NPS)	http://www.invasivespeciesinfo.gov/docs/news/teamtam/grantsdoi.doc	Rivers, Trails, and Conservation Assistance Program	US		☐	☐	☐	☑	☐	☐
NPS	www.nps.gov	Challenge Cost Share	US	$7,000 to $21,000, 1:1 non-federal match required	☐	☐	☐	☑	☐	☐

Organization	Website	Funding Name	Geography	Award Range	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
U.S. Fish and Wildlife Service (USFWS)		Private Stewardship Grants	US	10% non-federal match required				✓		
USDA	www.nrcs.usda.gov/programs/whip	Wildlife Habitat Incentives Program (WHIP)	US	Up to 75% Cost Share.				✓		
USDA	http://wsare.usu.edu/	Sustainable Agriculture Research and Education (SARE)	Western US	$15,000 to $150,000		✓		✓	✓	
USDA	grants.gov	Expert Integrated Pest Management Decision Support System	US	$146,000				✓	✓	
USDA	grants.gov	Invasive Species Management: Program of Research on the Economics of Invasive Species Management (PREISM)	US	$50,000 to $250,000				✓	✓	
USDA with technical support from NRCS		Conservation Reserve Enhancement Program (CREP)	US	A Federal annual rental rate is offered, plus cost-share of up to 50% of eligible costs.				✓		
USDA Animal and Plant Health Inspection Service (APHIS)		Pest Detection (Cooperative Agricultural Pest Survey-CAPS)	US					✓	✓	
USDA APHIS		Various Plant Health Programs	US					✓	✓	

Organization	Website	Funding Name	Geography	Award Range	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
USDA Cooperative State Research, Education and Extension Service (CSREES)	http://www.invasivespeciesinfo.gov/docs/toolkit/usdagrants2007.pdf	National Research Initiative – Biology of Weedy and Invasive Species in Agroecosystems	US		☐	☐	☐	☑	☑	☐
USDA CSREES	http://www.invasivespeciesinfo.gov/docs/news/teamtam/tamarisk%20grants%20ARS,%20CSREES,%20FS.doc	Regional Integrated Pest Management Competitive Grant Program	US		☐	☐	☐	☑	☑	☐
USDA Forest Service (FS)	http://www.invasivespeciesinfo.gov/docs/toolkit/usdagrants2007.pdf	Cooperative Forest Health Management Program	US		☐	☐	☐	☑	☐	☐
USDA Natural Resources Conservation Service (NRCS)	http://www.invasivespeciesinfo.gov/docs/toolkit/usdagrants2007.pdf	Wetlands Reserve Program	US	Options are permanent easement, 30-year easement, and restoration cost-share agreements.	☐	☐	☐	☑	☐	☐
USDA NRCS		Conservation on Private Lands Program		50% match required	☐	☐	☐	☑	☑	☐
USDA NRCS	http://www.nrcs.usda.gov/	Watershed Surveys and Planning	US		☐	☐	☐	☑	☐	☐
USDA NRCS	www.usda.gov	Environmental Quality Improvement Program (EQIP)	US	EQIP may cost-share up to 75% of the costs of certain conservation practices.	☐	☐	☐	☑	☐	☐
USDA NRCS		Plant Materials Program	US		☐	☐	☐	☑	☑	☐

Organization	Website	Funding Name	Geography	Award Range	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
USDA NRCS	http://www.nrcs.usda.gov/programs/cig/	Conservation Innovation Grants	US	$75,000 to $500,000 Max $1 Million	☐	☐	☐	☑	☐	☐
USDA NRCS	http://www.nrcs.usda.gov/programs/glci/	Funding for the Management and Control of Invasive Species Affecting Grazing Lands	US	$50,000 to $500,000	☐	☐	☐	☑	☐	☐
USDA NRCS	www.nrcs.usda.gov/programs/cpi/index.html	Conservation Partnership Initiative (CPI)	US	$100,000 to $200,000, 1:1 non-NRCS match required.	☐	☐	☐	☑	☐	☐
USDA NRCS		Conservation Technical Assistance (CTA)	US		☐	☐	☐	☑	☐	☐
USDA NRCS and FS		Grassland Reserve Program (GRP)	Grasslands		☐	☐	☐	☑	☐	☐
USDA, Economic Research Service (ERS)	http://www.invasivespeciesinfo.gov/docs/toolkit/usdagrants2007.pdf	Program of Research on the Economics of Invasive Species Management (PREISM)	US		☐	☐	☐	☑	☑	☐
USFWS	http://www.grants.gov/search/search.do?oppId=13106&mode=VIEW	Colorado Fish and Wildlife Management Assistance	CO	Cost share of 50% encouraged but not required	☐	☑	☐	☑	☑	☐
USFWS	http://www.fws.gov/birdhabitat/Grants/NAWCA/index.shtm	North American Wetlands Conservation Act Grants Program (NAWCA)	US	Max $75,000, 1:1 non federal match required	☐	☐	☐	☑	☑	☐

Organization	Website	Funding Name	Geography	Award Range	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
USFWS		Partners for Fish and Wildlife	US	1:1 Match	☐	☐	☐	☐	☐	☐

Congress Chartered Foundations

Organization	Website	Funding Name	Geography	Award Range	Adv	Edu	Pol	Dir	Res	SU
National Environmental Education Foundation (NEEF)	www.neetf.org		US		☐	☑	☐	☐	☐	☐
National Fish and Wildlife Foundation (NFWF)	www.nfwf.org	United States Golf Association Wildlife Links	US, Golf Courses	Max $30,000, 1:1 non federal match required	☐	☐	☐	☑	☑	☐
National Forest Foundation (NFF)	www.natlforests.org	Matching Awards Program (MAP)	US	$500 to over $100,000, 1:1 non federal match required	☐	☑	☐	☑	☐	☐
National Parks Foundation (NPF)	www.nationalparks.org		National Parks		☐	☑	☐	☑	☐	☐
NFF	www.natlforests.org	Wilderness Stewardship Challenge	US	Max of $50,000,1:1 non federal match required	☐	☑	☐	☑	☐	☐

Organization	Website	Funding Name	Geography	Award Range	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
NFWF	www.nfwf.org	Bring Back the Natives	US	2:1 non federal match required	☐	☐	☐	☑	☐	☐
NFWF	www.nfwf.org	Community Assistance Program (CAP)	US	$5,000 to $15,000, 1:1 matching funds required	☐	☑	☐	☑	☐	☑
NFWF	www.nfwf.org	ConocoPhillips SPIRIT of Conservation Migratory Bird Program	ConocoPhillips Presence	Min $25,000, 1:1 non federal match required	☐	☐	☐	☑	☐	☐
NFWF	www.nfwf.org	Five Star Restoration Challenge	US	$5,000 to $20,000	☐	☑	☐	☑	☐	☐
NFWF	www.nfwf.org	Keystone Initiative	US	$50,000-$300,000, 2:1 non federal match required	☐	☑	☐	☑	☐	☐
NFWF	www.nfwf.org	Native Plant Conservation Initiative (NPCI)	US	$10,000 to $50,000	☐	☑	☐	☑	☐	☐

Organization	Website	Funding Name	Geography	Award Range	*Adv*	*Edu*	*Pol*	*Dir*	*Res*	*SU*
NFWF	www.nfwf.org	Pulling Together Initiative	US	$5,000 to $20,000	☐	☑	☐	☑	☐	☐
NFWF	www.nfwf.org	State Comprehensive Wildlife Conservation Support Program	US		☑	☐	☑	☑	☐	☐
NFWF, USFWS, National Wildlife Refuge System, National Conservation Training Center (NCTC), and National Wildlife Refuge Association	http://www.fws.gov/refuges/education/natureOfLearning/index.html	The Nature of Learning	US	$10,000 for start-up; $5,000 for continuing	☐	☑	☐	☐	☐	☑

Tamarisk Toolbox
Appendix B:

Located on CD:
Riparian Restoration: Assessment of Alternative Technologies for Tamarisk Control, Biomass Reduction and Revegetation January 2008
Prepared by Tamarisk Coalition

Appendix D:

Wildfire Effects on Watershed Hydrologic Processes: An Introduction for Hydraulic Engineers, Watershed Managers and Planners

Wildfire Effects on Watershed Hydrologic Processes: An Introduction for Hydraulic Engineers, Watershed Managers and Planners

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March 2008

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prepared by

Desert Research Institute, Nevada System of Higher Education

prepared for

U.S. Army Corps of Engineers

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EXECUTIVE SUMMARY

Wildfires are an increasingly important issue, especially in the western United States, due to their threat to life either by direct impact of the fire on humans and their property or, indirectly, by causing less-favorable living conditions in an area. For example, wildfires can change hydrologic conditions of an entire watershed for years, with subsequent risks for downstream flooding as well as erosion, debris flow, and landslides, all of which threaten downstream communities.

The goal of this study was to (1) provide an overview of how wildfires affect watershed hydrology; (2) review current approaches to quantify wildfire effects on watershed hydrology geared towards solving watershed hydraulic engineering problems like flooding, erosion, sediment and debris yield as well as landslides; (3) analyze available data on the persistence of wildfire effects on soil hydrologic properties as a basis to derive a "wildfire effect recovery function"; and (4) identify current gaps of knowledge and outline how to fill them within upcoming research efforts. All four objectives have been addressed based on an extensive literature review.

From a hydrologic point of view, the following wildfire effects are important:

- Loss of vegetation and soil surface cover decreases interception and allows more water to reach the mineral soil surface.
- Decrease in infiltration capacity due to loss of soil surface cover, surface crusting, or formation of a water-repellent layer.

Wildfires in a watershed generally lead to:

- Higher peak flows and potential risk for flooding due to increase in net precipitation, decrease in infiltration capacity, and subsequent increase in surface runoff and sediment transport ("bulking").
- Increase in soil erosion and sediment yield due to loss of soil surface cover, soil structure deterioration, and surface runoff.
- Debris flow due to surface runoff and increased sediment yield due to erosion and landslides.
- Decrease in slope stability and increasing probability for landslides due to loss of stabilizing vegetation and increase in soil water content.

The effects of decreased interception and infiltration capacity on the hydrologic response of a watershed vary depending on the (a) portion of the watershed affected by the fire, (b) severity of the fire in the respective areas, and (c) timing, intensity and duration of the first storm after the fire and subsequent storms. For example, a severely burned watershed might respond with little increase in peak flow, debris flow or erosion if after the fire no intensive storm event occurs before the soil has been revegetated and other short-term fire effects have gone. Reversible fire effects like temporal loss of vegetation and surface cover, soil surface crusting, and water-repellent layers last between weeks and years, depending on

climate conditions, fire severity, vegetation, and soil type. Potentially irreversible changes occur if soil surface crusting suppresses any seed germination. The soil could be permanently lost due to erosion or invasive species could replace native species.

The effects of fire on soil hydraulic properties are fairly well understood and can be measured and modeled at the laboratory and small test plot scale in the field. A variety of approaches ranging from empirically based models (USDA, BEAR) to semi-empirical models (MODRAT, FEMA, SCS_CN, SWAT) and process-oriented models like KINEROS2 and MIKE SHE are already available to assess and predict wildfire effects on watershed hydrology, particularly base and peak flow in streams and sediment yield. Case studies showed that "standard" watershed hydrology models, using modified input parameters, and initial and boundary conditions to account for fire effects, can simulate observed post-fire effects on watershed hydrology.

To assess and predict wildfire effects on watershed hydrologic processes, it is recommended that currently available modeling frameworks like SCS-CN, AGWA, and MIKE SHE, which deal with hydrologic processes at the watershed-scale, are employed, and individual hydrologic parameters are adjusted to account for fire effects. For further improved modeling of wildfire effects on watershed hydrology, there is need for (a) quick and reliable methods to determine fire-induced changes in soil hydraulic properties, (b) better representation of water infiltration into multi-layer soils, and (c) improved schemes to scale up from plot-size to the watershed-scale soil hydraulic properties.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

Wildfires are an increasingly important issue, especially in the western United States, due to their threat to life either by direct impact of the fire on humans and their property or, indirectly, by causing less-favorable living conditions in an area. For example, wildfires can change hydrologic conditions of an entire watershed for years, with subsequent risks for downstream flooding as well as erosion, debris flow, and landslides, all of which threaten downstream communities.

Although fire effects on ecosystems have been studied to different extents as reviewed by DeBano *et al.* (1998), Neary *et al.* (2005a) and others, quantitative understanding and application of tools to assess and predict the hydrologic response of wildfire-affected watersheds are still very limited. Empirically based approaches to estimate post-fire peak flow and sediment yield have been around for quite some time (e.g., USDA, 1949). Simple models to predict fire effects on watershed hydraulic responses have been developed for southern California (LACDPW, 1991a,b; FEMA, 2003). However, more process-oriented expertise on wildfire impacts on watershed hydrology is necessary to expand the capabilities of hydrologic models to improve the predictions of fire-related changes in peak flow of water, sediment, and debris, or to assess changes in slope stability. First-case studies show that process-oriented models will expand the capabilities of currently available approaches to assess wildfire impact on ecosystems (Neary *et al.*, 2005a) and post-burn flood risk assessment (Canfield and Goodrich, 2005; Guardiola-Claramonte, 2005).

One of the difficulties in predicting post-fire impacts is that available knowledge on quantifying post-fire watershed hydrology is still very scattered among disciplines (agriculture, forestry, soil sciences, hydrology) and therefore difficult to access for practitioners like hydraulic engineers, and watershed managers and planners in need of practical solutions. Often, a better understanding of some basic hydraulic processes (interception, infiltration, and runoff) helps in the first estimate of how fire might affect hydraulic properties of a watershed. Also, key questions often asked are how long fire-effects potentially last and whether a watershed ever reaches its pre-fire hydrologic conditions. Therefore, the goal of this study was to: (1) provide an overview of how wildfires affect watershed hydrology; (2) review current approaches to quantify wildfire effects on watershed hydrology geared towards solving watershed hydraulic engineering problems like flooding, erosion, sediment, and debris yield as well as landslides; (3) analyze available literature data on the persistence of wildfire effects on soil hydrologic properties as a basis to derive a "wildfire effect recovery function"; and (4) identify current gaps of knowledge and outline how to fill them within upcoming research efforts. Goals (1) through (4) have been addressed by literature review.

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2. WILDFIRE EFFECTS ON VEGETATION AND SOIL

Wildfires have been defined as those burns that do not meet management objectives (in contrast to prescribed fires) and that usually require a suppressive response (Neary *et al.*, 2005a). The reason for focusing on wildfires in this study, rather than prescribed fires, is that the former typically have more severe, unpredictable, and long-lasting impact on watershed hydrology. Additionally, it is not uncommon to lose control of a prescribed fire, resulting in a wildfire.

A wildfire typically evolves through five phases during its existence (Figure 1) (DeBano *et al.*, 1998). The first phase, pre-ignition, involves fuel heating that results in dehydration and pyrolysis, which is defined as the decomposition or transformation of a compound caused by heat. To ignite a wildfire, fuel (in the form of dead and live standing biomass, fallen logs, and surface litter), oxygen, and heat all must be present.

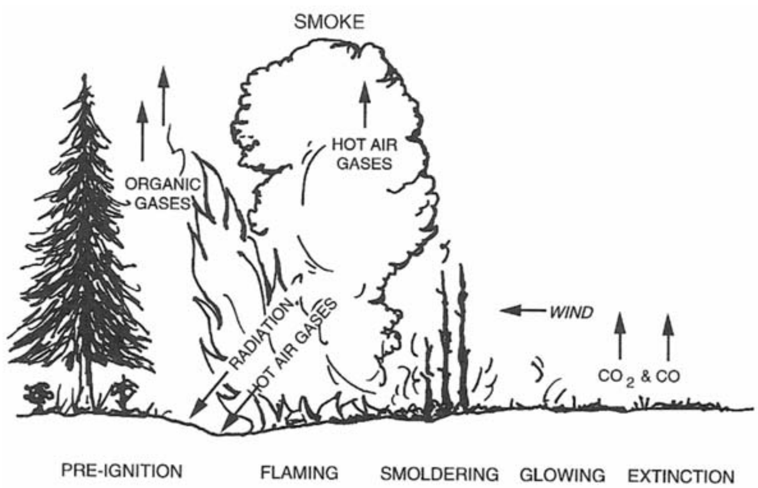

Figure 1. Phases of the existence of a fire (adapted from Johansen *et al.*, 1985).

Once ignited, the fire will continue as a two-stage thermal process of continuing pyrolysis and combustion, the latter including three phases: flaming, smoldering, and glowing (Figure 1). Pyrolysis continues during flaming, diminishes during smoldering, and virtually ceases in the glowing phase, followed by the final phase know as extinction (DeBano *et al.*, 1998). Important terms in this context are fire intensity and severity as well as burn intensity and severity. According to Davis and Holbeck (2001), fire intensity accounts for fire effects on overstory vegetation and describes the rate of heat release from combustion per unit time and unit length of a fire front. Fire intensity depends upon the rate of spread, heat of combustion, and total amount of fuel consumed. Fire intensity is defined on a relative scale: low = up to 0.25-inch-diameter fuels consumed; moderate = greater than 0.25-inch, but less than 0.75-inch-diameter fuels consumed; high = 0.75-inch-diameter and larger fuels consumed (Davis and Holbeck, 2001). Fire severity is a relative measure of the degree of change in overstory vegetation caused by fire intensity and is referred to as low, moderate, or high fire severity. Burn intensity accounts for fire effects on understory (ground) vegetation and soils (Davis and Holbeck, 2001). Burn intensity depends upon moisture content of duff and large fuels (lying on the ground) and accounts for the amount of conductive and radiant heat that reaches the soil surface. The amount of duff consumed and depth and color of char and ash are visible indicators. Burn intensity is qualitatively defined on a relative post-fire burn severity scale: low (or partial consumption) = black ashes; moderate = gray or mixed ashes; high = white or red ashes (Davis and Holbeck, 2001). Finally, burn intensity is in part defined by its effect on ecosystems, e.g., a function of plant responses to fire. Burn severity is a relative measure of the degree of change in a watershed that relates to the severity of the effects of the fire on soil and watershed conditions. It is delineated on topographic maps covering the area of the fire as a mosaic of polygons labeled high, moderate, and low burn severity.

Different phases of combustion have different impacts on vegetation and soil and, therefore, on the hydrologic response of watersheds. Flames consume above-ground biomass by releasing large amounts of energy in a short amount of time (high fire intensity). Smoldering affects organic matter on and within the soil surface; it is a less intensive form of combustion but it can last much longer than flaming and, therefore, it has a larger impact on the soil and its physical properties (i.e., just 10 to 15 percent of the above-ground-generated heat reaches the soil surface [Neary *et al.*, 2005b]). Due to the high heat capacity of the soil and low thermal conductivity, the soil surface has to be heated for a long time before the heat penetrates the soil and cause changes to its physical properties.

2.1 Effects on Vegetation

Depending on fire and burn severity, the heat produced by wildfires burns live or dead vegetation (trees, shrubs, grass) to different degrees, from a transient loss of leaves to complete death of the plant (Bond and Van Wilgen, 1996; Neary *et al.*, 2005a). Particularly in the southwestern US, severe fires can destroy as much as 90 percent of the vegetation and litter cover (Robichaud *et al.*, 2000). Due to leaf loss, plant transpiration can be reduced either for a single growing season (low fire severity) or permanently if the plant dies (high fire and burn severity). Besides the decrease in transpiration due to leaf loss, interception by the vegetation canopy decreases and increases the amount of precipitation that reaches the soil surface. The lack of transpiration generally leads to wetter soil conditions until the soil is revegetated. Vegetation-related changes in water content may be either short term or long term depending on the regrowth of the plant community and its composition and density after the fire. The vegetation that regrows after a fire may be different from the original plant community and consequently requires a different water demand. This could lead to short-term evapotranspiration changes if the regrowth will ultimately be replaced by the original plant species. However, in the case that destroyed vegetation is permanently replaced by new species, there will be a change in the long-term water balance over time. Besides negative effects, it is worth mentioning that wildfires can also generate benefits to vegetation, particularly in the long term. Many plants regrow quickly following wildfires, because fire converts organic matter to readily available mineral nutrients. Also, fires often increase vegetation diversity.

2.2 Effects on Soil

Wildfires can affect the soil and its mechanical and hydraulic properties in three different ways by (1) partially or totally removing the litter and duff horizon at the soil surface, (b) altering soil structure of the underlying horizons, and (3) forming a hydrophobic layer due to the burn. The litter horizon (Figure 2) consists of an accumulation of non-degraded organic material like dead wood, leaves, etc. Litter horizons are found mostly in semi-arid and arid climates. Duff horizons are similar to litter horizons but form under more humid climates and acidic soil conditions. Fermentation and humus horizons consist of organic material that has been degraded to some extent. Litter and duff are the primary fuel for combustion close to the soil surface.

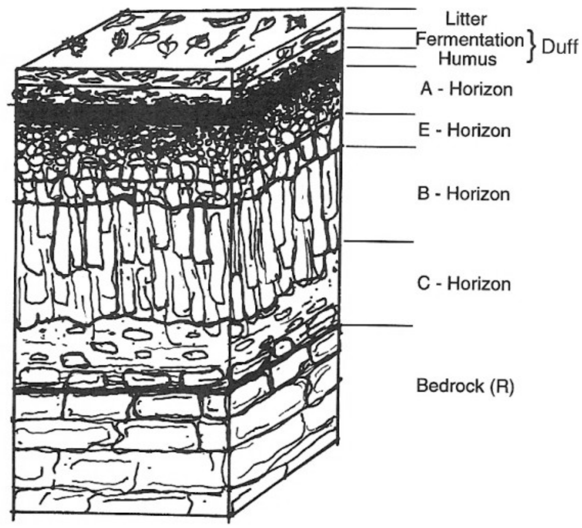

Figure 2. A soil profile showing organic matter accumulation (litter and duff [i.e., fermentation and humus] horizon) and mineral soil horizons (taken from DeBano *et al.*, 1998).

Depending on burn intensity, litter and duff are burned to different degrees, varying from light charring to complete combustion and therefore removal. In this latter case, a layer of light-grey to white ash is left behind, indicating that the wildfire reached the highest burn intensity or severity level. With the loss of litter and duff, the mineral soil surface loses its cover that stores and redistributes precipitation before it infiltrates, and protects against the direct impact of raindrops, which fosters soil structure deterioration.

Altered soil structure is the second soil property considerably impacted by wildfire. A mineral soil profile (Figure 2) is typically subdivided into several horizons with different internal structure (individual mineral grains, aggregates, peds). This structure has a significant influence on the soil mechanical and hydraulic properties governing water and gas flow, and nutrient transport. Of special interest in the context of wildfires is the A-horizon, found directly underneath the litter or duff horizon. The A-horizon features a particularly porous structure due to aggregation of mineral particles with subsequently higher infiltration capacity. Especially under humid climate conditions, the mineral particles are "glued" together with organic substances that have accumulated within the A-horizon over the years. Depending on burn intensity, these organic substances are combusted, causing the A-horizon to lose its aggregate structure. Consequently, soil porosity, permeability, and strength of the soil decrease, which leads to a decrease in water storage and infiltration capacity and an increase in erosion susceptibility. The first runoff-producing rain event occurring after an intensive burn tends to destroy the exposed aggregates and fosters erosion of finer mineral particles from the soil surface. Furthermore, the rain event can leave the surface with a hard crust, which has a much lower hydraulic conductivity and therefore infiltration capacity than the original aggregated soil. Closely related to soil structure alterations is the clogging of soil macropores due to fire residues like ash, charcoal, and aggregate-borne fine soil particles.

Water repellency or hydrophobicity is the third soil property likely to be changed due to fire. According to DeBano (1981, 2000) a water-repellent (or hydrophobic) layer forms within a soil when volatile organic compounds, formed through pyrolysis of litter and duff during the burn, diffuse into the soil along the thermal gradient (i.e., higher temperature at the soil surface than in the subsurface during the fire), condense in cooler areas and "impregnate" mineral soil surfaces with an organic coating. These coatings convert the surface wettability from wettable to water-repellent (Figure 3). Extensive water-repellent layers are formed under smoldering fires, combusting resin-rich fuel over coarse-textured mineral soils. Once established, the water-repellent layer acts as a capillary barrier and decreases infiltration capacity of the soil, similar to a coarse-structured horizon between two fine-structured soil horizons.

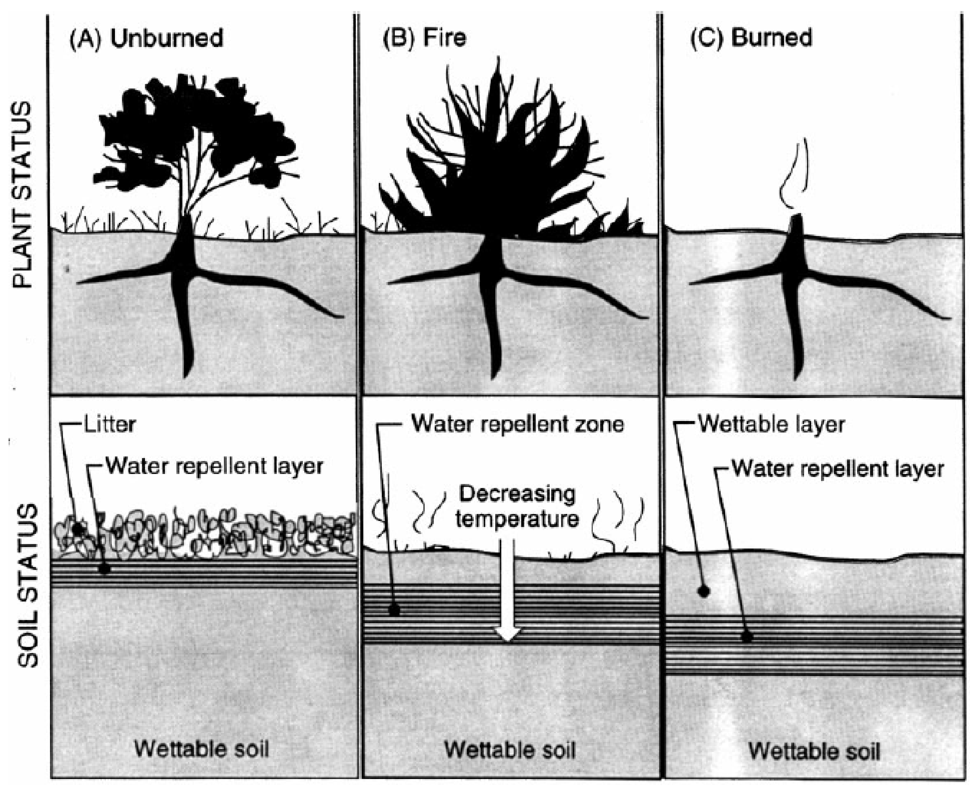

Figure 3. Formation of a water-repellent soil layer as a result of a fire (taken from DeBano, 2000).

3. WILDFIRE EFFECTS ON WATERSHED HYDROLOGIC PROCESSES

This chapter provides a more detailed description of wildfire effects on key processes of the hydrologic cycle (interception, infiltration, surface runoff, evapotranspiration, and water storage) and their implications for post-fire flooding, erosion, sediment, and debris yield, as well as landslides with subsequent risks to human health and property.

3.1 Interception

Interception is the hydrologic process by which vegetative canopies, understory, and accumulated litter and duff on the soil surface interrupt or delay the arrival of precipitation to the mineral soil surface. In many cases, the water lost through interception evaporates back to the atmosphere and no longer plays a role on the local hydrology (Neary and Ffolliott, 2005). Interception thus acts as a reservoir that reduces the amount and intensity of the net precipitation that reaches the soil surface and, therefore, reduces peak surface runoff or channel flow and, eventually, flood risk. It is accounted for in hydrologic models in the loss rate. Interception usually holds back only a small portion of the total precipitation, changing with vegetation type and density. In arid and semi-arid shrublands and grasslands, interception loss is generally less than 10 percent of the total annual rainfall (DeBano and Neary, 2005), but for some coniferous canopies, the ratio can be as high as 48 percent (Hormann *et al.*, 1996). Interception also reduces the energy that raindrops possess as they strike the soil surface. This buffering mechanism decreases the possibility for splash erosion and crust formation of fine-textured soils.

Wildfires burn vegetation canopy and understory as well as the litter and duff accumulation on the soil surface and reduce their interception effect (Bond and Van Wilgen, 1996; Pyne *et al.*, 1996; DeBano *et al.*, 1998). After severe wildfires, interception is lost completely when vegetation, litter and duff, and leaves are burned off and the mineral soil surface remains bare or covered only with a layer of ash. Without the buffering and distributing effect of interception, precipitation reaching the soil surface increases and can more rapidly reach or exceed soil infiltrability (see next section). Fire effects on interception will be temporally variable if plants either survive the burn but lose their leaves for a single season, or if severely burned areas are "islands" of limited size onto which vegetation can spread from within less affected areas. These isolated areas burned to various degrees become important when averaging the impact of fires over larger areas. Also, care must be taken to not average over larger areas if it would make a discernible difference on landscape characterization and where intermediate results need to be attained. If the soil surface deteriorates due to the fire limits or suppresses seed germination or if the (top-)soil has been washed away by erosion, leaving behind less fertile subsoil or even parent material, re-vegetation will be limited and interception might be lost permanently (Cerdà and Doerr, 2005).

3.2 Infiltration

Precipitation that reaches the surface will evaporate, infiltrate, or run off the soil surface. Infiltration, defined as the volume of water entering a specified cross section of soil per unit time (Soil Science Society of America, 2007), is a key process that affects the hydrologic response of a fire-affected watershed. Higher infiltration rates reduce rapid surface runoff and, therefore, mitigate surface water peak flow and, subsequently, debris flow and flooding. Infiltration occurs because of the integrative action of gravity and soil capillary pressure on the water of a partially saturated soil. As an essential property of a dry and wettable porous medium, soil exerts negative capillary pressure that "pulls" the water into dry pores. This so-called "water suction" (or soil water potential) is lower (more negative) when the soil is dry (or partially saturated) and approaches zero as soil becomes fully saturated. During early times of an infiltration event, the gradient of capillary pressure head is larger than the gradient of gravity head. Therefore, when infiltration into dry soil begins, the infiltrability is maximal and dominated by the capillary pressure gradient. The influence of capillarity diminishes with time because suction gradually becomes less negative as the soil water content increases. Gravity then becomes a dominant force that drives infiltration and percolation of water. It is important to note that even if the infiltration rate is high, surface runoff can occur if precipitation intensity exceeds infiltrability.

In addition to the soil water potential, soil hydraulic conductivity is also an important parameter in the infiltration process. Whereas the driving force of suction becomes smaller with increasing soil water content, hydraulic conductivity increases. This is because more pore space is water filled and, therefore, allows water to flow through the soil easier. Hydraulic conductivity approaches its maximum ("saturated hydraulic conductivity") as the soil reaches saturation. Under water-saturated conditions, infiltration rate is gravitationally controlled and, therefore, becomes constant (assuming that the ponding depth on the surface is constant). This means that the infiltrability for a wettable soil is highest when it is dry, and lower as the soil water content increases.

Water potential (suction), water content, and hydraulic conductivity are coupled and change significantly during infiltration. The nonlinear relationships between these parameters make characterization of infiltration difficult to achieve and predict, especially when considering that soils and these relationships are spatially and temporally heterogeneous, which adds an additional layer of complexity when quantifying infiltration rates and amounts.

Using the above discussion, it is clear that wildfires affect the soil in several fundamental ways, which in turn affect the infiltration capacity. According to the literature reviewed, changes in infiltration capacity are due to the following factors: loss of soil surface protection, soil structure deterioration, and water repellency.

3.2.1 Loss of Soil Surface Protection (Vegetation, Litter, and Duff)

Soil surfaces that are covered by vegetation canopy and litter and duff decrease the mechanical impact of raindrops, redistribute and "homogenize" net precipitation over a larger area, and prolong time available for infiltration during a storm event. The loss of the natural (pre-fire) soil cover can be of special importance where the soil surface already has limited infiltrability (e.g., fine-textured soil with weakly developed secondary structure) or where the soil surface is "naturally" water-repellent, for example in arid or semi-arid areas with grass and shrub-type vegetation (Pierson *et al.*, 2001). In these cases, the soil cover helps to "pre-condition" and "compensate" for the negative effects of poor surface structure or water repellency of the mineral soil on infiltration capacity. If the surface cover is removed completely by wildfires, the already limited infiltration capacity will be exceeded more quickly, causing more severe surface runoff.

3.2.2 Deterioration of Soil Structure

Deterioration of soil structure is strongly related to the loss of cover that protects the soil surface against direct raindrop impact, and reduces exposure of the mineral surface to heat by fire or direct sunlight. When directly exposed to raindrop impacts, fine-textured (silt- and clay-rich) soils tend to lose their aggregate structure and form surface crusts, which are just a few millimeters thick but which can effectively seal the soil surface. These effects were observed by Garcia-Corona *et al.* (2004) when the soil surface in their study was exposed to high temperatures during severe wildfires. They showed that the aggregate structure deteriorated from the combustion of organic substances within soil aggregates, clay structure changed from loss of intermolecular water layers, and the remaining mineral particles either eroded from the soil surface or sealed it when exposed to water. Morin and Benyamini (1977) and Neary *et al.* (1999) pointed out that fire residues like ash and charcoal can clog soil macropores and, therefore, considerably affect infiltration capacity of a soil.

3.2.3 Water Repellency

As discussed in Chapter 1, water-repellent (also called "hydrophobic") layers may form during wildfires. Once the soil becomes hydrophobic, water no longer enters soil pores due to capillary attraction. Rather, water must enter the pores under positive pressure, much in the same way that water percolates through a fine-textured layer and enters a coarse-textured layer (Figure 4). Similar to percolation through a layered soil, a wetting front will move through the wettable layer rapidly until it reaches the water-repellent layer, after which the infiltration rate drops to that of the water-repellent soil (see also Figure 3). The infiltration rate remains depressed until the wetting front passes through the water-repellent layer into the underlying wettable soil; then the rate begins to increase (DeBano, 2000) to a rate limited by the soil with the lowest hydraulic conductivity. The wetting fronts that occur in water-repellent soil are most likely nonhomogeneous and unstable (Figure 4), which makes water movement rather difficult to predict. For more details on infiltration into water-repellent sandy soils and wetting front instability, see e.g., Ritsema and Dekker (1994, 2000) and Bauters *et al.* (2000).

The degree of hydrophobicity depends on fire intensity, burn severity, initial soil moisture content, vegetation type, soil texture, and time since burning (DeBano, 2000). High burn severity fires will combust more organic matter, produce more heat and volatile organic compounds, and create a larger and more continuous hydrophobic layer.

The most intense formation of water-repellent layers has been observed in the temperature range between 175 and 205°C. At higher temperatures, water repellency is less pronounced and disappears at temperatures exceeding 290°C (Savage, 1974; DeBano *et al.*, 1976; Nakaya, 1982). For soil temperature less than 175°C, hydrophobicity increases with increasing temperature. The depth at which hydrophobic layer formation occurs depends on the degree of soil heating. Slow moving fires with high burn severity heat the soil to higher temperatures causing deeper formation (5 to 15 cm) of the condensed organic matter. Conversely, low burn severity ("cooler") fires typically move faster and cause volatized organic matter to condense near the soil surface (Scholl, 1975; MacDonald and Stednick, 2003).

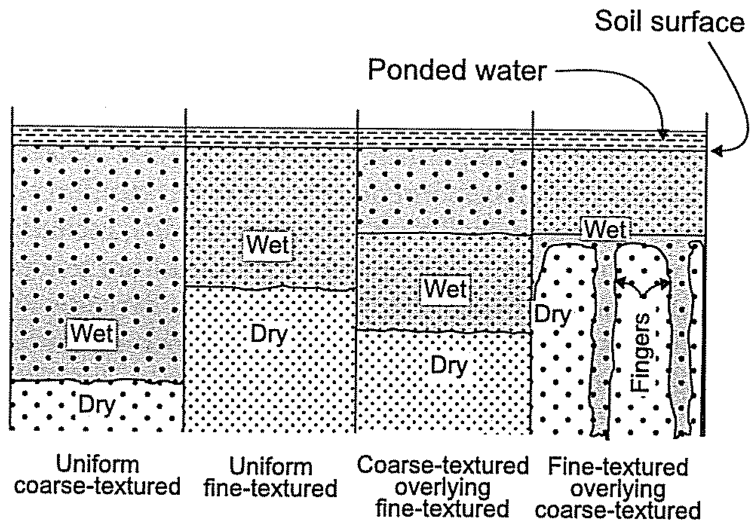

Figure 4. Appearance of nonuniform wetting front during infiltration into a layered profile with a fine-textured layer overlying a coarse-textured layer (taken from Hillel [1998]).

Robichaud and Hungerford (2000) studied in-depth the influence of soil surface temperature and water content on the formation of water-repellent layers within undisturbed soil cores of 305-mm diameter. They found that the temperature gradient within the soil depends on the initial water content and that higher soil water content results in deeper hydrophobic layers. Dry soil heats rapidly at the surface, but the heat travels slowly due to low thermal conductivity. Conversely, wet soil heats up slowly at the surface (especially until all the water is vaporized), but the heat front travels comparably faster due to higher thermal conductivity. Three surface heat treatments of 100 to 150°C, 250 to 300°C, and 400 to 500°C showed that the most pronounced water-repellent layer was formed in dry soil (10 to 20 mm deep) due to low heat treatment, whereas high heat treatment caused formation of a repellent layer deeper in the soil profile (30 to 50 mm deep) and with less burn intensity. MacDonald and Huffman (2004) found that soil moisture thresholds at which the transition from hydrophobic to hydrophilic soil condition occurs increase with increasing burn severity. Data from 45 sites in ponderosa and lodgepole pine forests of the northern Colorado Front Range suggest a threshold of approximately 10 percent gravimetric soil moisture content for unburned sites, 13 percent for sites burned at low severity and no less than 26 percent for burned sites at moderate and high severity.

With respect to soil texture, sand has been found most susceptible to hydrophobic layer formation. Studies of chaparral and ponderosa forests have shown that soils with higher sand content will result in higher degrees of hydrophobicity. Huffman *et al.* (2001) found that besides burn severity, fire-induced hydrophobicity is highly correlated to the sand content of a soil. These results could be explained, in part, because of the rather high hydraulic conductivity of dry sands (volatile organic compounds can be easier transported into a loose sand than a more compact silt or clay), and because sand has a lower surface area than silt or clay for a given amount of applied hydrophobic compound; therefore, more mineral soil surface area will be covered.

The factors controlling occurrence and extent of fire-induced water repellency (DeBano, 2000) are highly variable in space and time. Robichaud (2000) studied the effects of fire on infiltration rates after prescribed fires in forests in the northern Rocky Mountains. He used small-scale plots (1 m × 1 m in area) as test sites with different burn severity and found decreasing soil hydraulic conductivity with increasing burn severity (Figure 5). Considerable variability was observed because of the heterogeneous burn pattern and the presence of some surface crusting and sealing from raindrop impacts after the fire. When hydrophobic conditions occurred after a high-severity burn, saturated hydraulic conductivity was reduced to between 10 percent and 40 percent during the onset of simulated rainfall, thus

$$K_{hydrophobic} = C_{fire} \times K_{sat} \quad (1)$$

where $0.1 \leq C_{fire} \leq 0.4$.

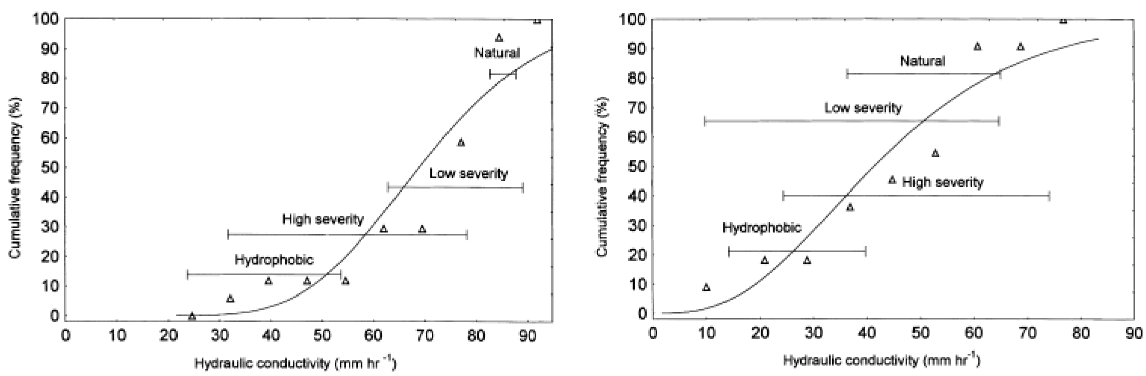

Figure 5. Hydraulic conductivity versus burn severity from the “Slate Point” (left) and “Hermada” (right) test sites (taken from Robichaud, 2000).

Regarding the importance of water repellency, Robichaud (2000) showed that, for forests in the northern Rocky Mountains, much of the fire-induced changes in hydraulic properties were associated with the change and disappearance of the litter and duff layers. According to DeBano (2000), fire-induced water repellency is the key factor that controls post-fire infiltration capacity for arid areas with coarse-textured soils and predominantly grass and shrub (“chaparral”) vegetation. Investigating 95 recently burned drainage basins in Colorado, New Mexico, and southern California, Cannon (2001) found only one basin with a laterally continuous water-repellent layer, concluding that “…the physical properties of the bare, burned soils, without the presence of water-repellent soils, are generally sufficient to cause low infiltration and high surface runoff in the areas studied.” Similar predominantly “low surface permeability” effects were reported by Wilson (1999).

3.3 Evapotranspiration and Soil Water Storage

Once infiltrated, water will be either stored within the soil profile, returned to the atmosphere through evaporation from the soil surface and transpiration through vegetation (collectively addressed as evapotranspiration, ET), or percolate further below the surface where it will reach groundwater and flow offsite or reappear as springs or surface flow (Figure 7). Although a wildfire has relatively little impact on overall evaporation (loss of vegetation leaves more soil exposed to the sun, which increases its temperature and evaporation rate; on the other hand, the drier soil surface has lower hydraulic conductivity, which reduces evaporation rate), transpiration is highly affected due to the loss of live leaves. Because transpiration is more efficient than evaporation for transporting water from the soil to the atmosphere, soil water content is typically higher in fire-affected soils than in nonaffected soils that support vegetation. For an initially wet soil, this higher water content decreases initial infiltration rate due to lower water potential gradient, whereas for an initially dry soil, an increase in water content after the fire might even increase infiltration capacity due to increasing hydraulic conductivity.

3.4 Surface Runoff

When precipitation exceeds infiltration, water can pond on the soil surface or flow downgradient as surface runoff, also called overland flow (Figure 6). This infiltration-excess runoff is generally referred to as Hortonian runoff. Surface runoff can also be generated when a shallow water table rises up to the soil surface during storm events and rain water no longer infiltrates. This is called saturation-excess runoff generation, or Dunnian runoff generation. Hortonian runoff is the dominant runoff mechanism in arid and semi-arid areas, while Dunnian runoff dominates in humid areas (Brooks *et al.*, 1991).

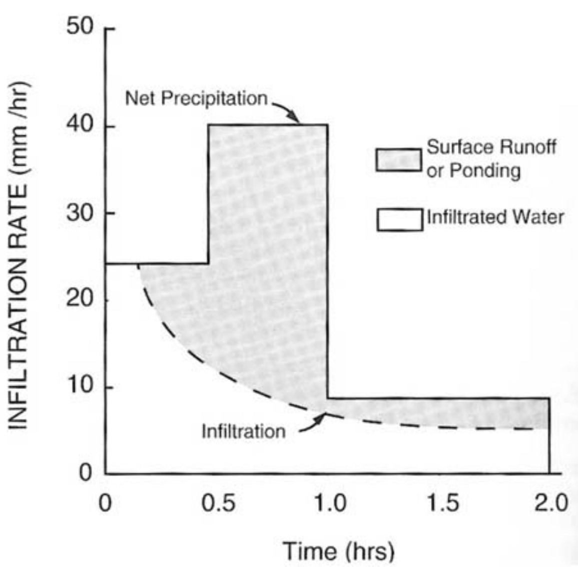

Figure 6. Relationship between precipitation and infiltration resulting in ponding and surface runoff (adapted from Brooks *et al.*, 1991).

Surface runoff is usually shallow and rapid. Runoff flow is usually driven primarily by gravity, whereas runoff routing is guided by the topography. The occurrence of rills or gullies on the hill slope will largely concentrate and accelerate water flow and energy and, therefore, increase the erosive capability of flow. However, surface conditions can greatly change this process. Densely vegetated areas have larger surface roughness values that impose extra resistance to the flow and dissipate flow energy. Vegetation also increases the soil stability and restricts the development of rills and gullies, therefore controlling the runoff in an indirect way. A wildfire will fundamentally change this system. Several studies have shown that post-fire surface runoff causes a substantial increase in flooding, debris quantities, and soil erosion for a period of time after the fire event (Krammes and Rice, 1963; Anderson *et al.*, 1976; Campbell *et al.*, 1977; Ffolliott and Neary, 2003). The text below provides specific descriptions of how wildfires can affect several aspects of surface runoff.

Runoff generated from a post-fire storm event can be much higher than before wildfires occur. Conedera *et al.* (2003) reported that the post-fire runoff in the first six months after wildfires can increase up to 10.3 times. According to Neary *et al.* (2005a), the largest increase in runoff yield (i.e., 14.2 times) was found in an Arizona watershed. This increase also means a larger runoff coefficient, defined as the ratio of runoff to precipitation. The increased runoff yield greatly changes the correlation between the rainfall recurrence frequency and the runoff frequency; for example, the fire may correlate the recurrence interval of a 100- to 200-year flood event to a 10-year rainfall event (assuming that for unburned conditions a 100-year rainfall event leads to a 100-year flood event).

Obviously, runoff increases due to decreasing infiltration and other fire effects, like loss of interception and surface cover, which increases at least the short-term risk for flooding for wildfire-impacted watersheds. To local flood control districts, this may lead to a need for remapping flooding risk areas and re-evaluating risk levels.

3.5 Soil Erosion and Sediment Yield

Erosion, defined as the detachment and movement of soil material by water, wind, ice, or gravity (Soil Science Society of America, 2007), has a direct and significant impact on watershed hydrology. Erosion after a wildfire can be initiated by raindrop splashing, where raindrops either remove soil particles or weaken the stability of soil peds (see also Chapter 2.2.2 on structure deterioration) and ready them to be transported by surface runoff, wind, or gravity. Severe erosion occurs when surface runoff is collected in rills, channels and gullies where more soil can be eroded due to higher water flow energy and exerted shear stresses than due to rather low energy sheetflow. The main effect of post-fire erosion on watershed hydrology is (a) loss of fertile soil for revegetation, (b) formation of sediment yield, and (c) change of surface morphology (formation of rills and gullies as fast water drainage paths).

Post-fire soil erosion occurs because of altered soil properties, reduced vegetation, increased runoff discharge, and a larger sediment delivery area. In some regions of the US, over 60 percent of erosion across the total landscape is fire related (Neary *et al.*, 2005a). In undisturbed forested areas, the baseline erosion rate is usually very low. For post-fire situations in watersheds of the western United States (Washington, California, and Arizona), erosion rates 10 to 1,000 times the baseline erosion rates were summarized by Neary *et al.* (2005a). Campbell *et al.* (1977) reported a 416-fold increase in sediment yield after wildfires in southwestern ponderosa pine ecosystems. The erosion intensity generally decreases with time and returns to the pre-fire level after several years. However, the highest erosion rates may not occur in the first year following the fire, if intensive rainfall events do not occur. In these cases, higher rates may occur in the second or third year after wildfires, depending on the characteristics of the storm event. It has been noticed that sediment and debris yield of the first flood after the burn is much higher than under unburned conditions. However, if a second flood event follows shortly after the first, there is a significant decrease in sediment and debris yield from the watershed. This leads to the conclusion that sediment eroded under unburned conditions accumulates together with debris within rills and gullies and behind vegetation from where it is easily released by the first post-fire flood - even due to relatively small events.

3.6 Stream Flow

Water for stream flow has several possible sources: direct interception of rainfall, surface runoff from land surface, interflow from the vadose zone, or base flow from groundwater (Figure 7). Stream flow typically transports surface water away from a watershed to larger surface water bodies such as lakes and oceans.

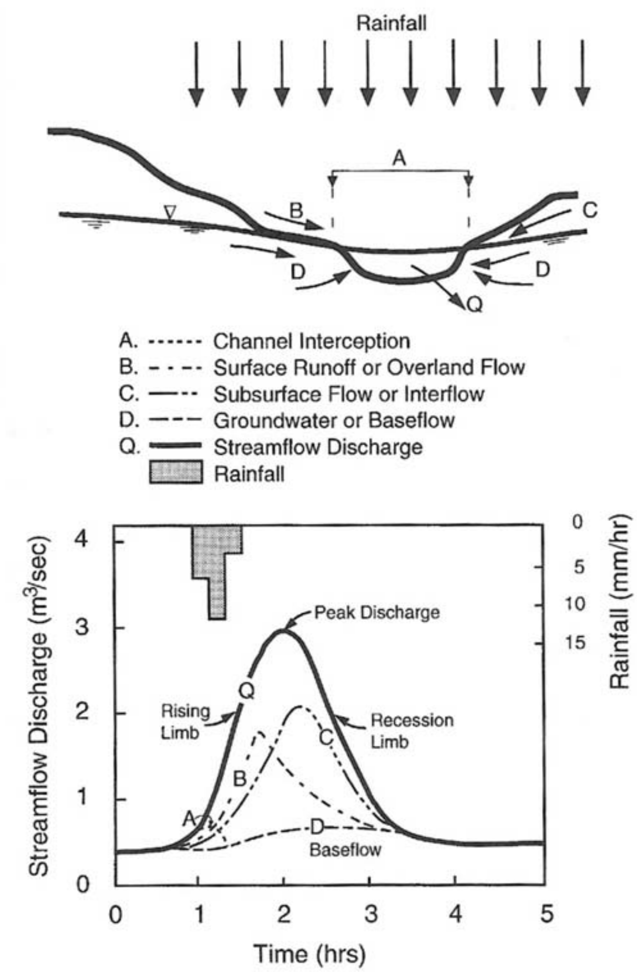

Figure 7. Relationship between pathways of flow from a watershed and the resultant stream flow hydrograph (adapted from Brooks *et al.*, 1991).

Wildfires can either positively or negatively affect these sources. For example, by changing the soil hydraulic properties, the fire suppresses infiltration rates and potentially reduces base flow. On the other hand, due to the destroyed vegetation, post-fire evapotranspiration is decreased, which increases soil water storage and hence deep recharge and (potentially) base flow. Limited research findings from sites that underwent prescribed burns indicate that base flow increases after wildfires. Also, anecdotal reports have shown springs beginning to flow after years of being dry (Neary *et al.*, 2005a). This implies that removing deep-rooted vegetation could alter the magnitude and direction of the hydraulic gradient and lead to higher groundwater recharge, which in turn would increase base flow.

Many observations have shown a significant increase in post-fire peak flows. The magnitude of increased peak flow varies widely. As summarized in Neary *et al.* (2005a), the factor of peak flow increase after wildfires varies from 0 (no change) to +2,232 (over 2,000 times higher). The cause of peak flow increase is a combination of several mechanisms. Aside from unusual rainfall events, the increased peak flow would be caused by higher post-fire runoff yield, and the reduction of vegetation and litter. As discussed previously, runoff yield usually increases for a post-fire storm event due to less infiltration. This implies an earlier runoff start and a higher peak flow for the same surface. Decreased vegetation and litter coverage results in lower roughness of the burned surface, leading to higher runoff velocity, which produces a shorter-duration hydrograph, a higher peak, and an earlier time to peak for the same rainfall event. Thus, it can be expected that the timing and magnitude of peak flow occurrence on burned lands is earlier and larger than in pre-fire cases, respectively. A study by Canfield *et al.* (2005) on post-wildfire data from the Marshall Gulch watershed near Tucson, Arizona, indicates that changes in runoff volume are small compared to changes in peak runoff, which supports the above-mentioned expectation. McLin *et al.* (2001) also noted that post-fire runoff peaks can be very high, whereas runoff volumes change to a lesser degree. Therefore, users of unit hydrographs tend to overestimate volume to accurately predict peak runoff rates.

3.7 Debris Flow

Costa (1988) defines debris flow as clear water flow containing more than 47 percent of sediment by total volume. Conventional water flow can carry up to 20 percent sediment by volume, while sediment loads between 20 and 47 percent are defined as hyperconcentrated flows. With increasing sediment load (up to about 55 percent per volume), debris flow behaves like a viscoplastic material that creeps rather than flows and with decreasing velocity for increasing sediment load. For sediment loads greater than 55 percent per volume, debris turns into a solid, moving by block sliding similar to landslides.

Debris flows from large storm events occur with little warning and can have significant environmental consequences. Some travel into residential areas, threatening human safety, damaging roads, houses, and property. Debris flows can significantly widen existing channels and gullies due to the increased volume and shearing effect of the sediment and debris as well as increased volume of clear water runoff that leads to increased erosion, as sediment starved flows travel downslope. Common mechanisms for debris flow initiation include: 1) entrainment of sediment or colluvium and erosion of channel material by runoff, 2) a “firehose-effect,” where concentrated runoff from bedrock mobilizes downslope material, and 3) mobilization from infiltration-triggered landslides.

Wildfires greatly increase debris flow hazards due to increased runoff, loss of vegetation, and decreased soil cohesion resulting from the loss of cementing agents (e.g., calcium carbonate, humic substances). In addition, wildfires increase debris flow frequency and intensity. Cannon *et al.* (2001) investigated debris flows at several sites in Colorado, Montana, New Mexico, and California and found four different debris flow triggering mechanisms in recently burned areas. These included:

1. Progressive bulking of storm runoff with material eroded primarily from burned hill slopes.
2. Similar to the above mechanism, but debris flows were comprised of material eroded primarily from channels.
3. Debris flows initiated as levee-lined rills developing near the crest on a broad, open hillslope. The levees, or inter-rill areas, consist of gravel- and cobble-sized material supported by an abundant fine-grained matrix. Debris flows were triggered in response to storm rainfall with approximately two-year recurrence.
4. Post-wildfire debris flows that are initiated by rainfall-infiltration triggered landslides.

Different mechanisms were observed in different areas. However, the dominant mechanisms (Cannon, 2001) are all related to surface runoff, which increases sediment entrainment. In addition, debris flows occur more frequently on steep slopes, where kinetic energy levels of flow can be higher. On the other hand, Chen and Young (2006) showed that total infiltration is generally larger on steeper slopes, mainly because, for a straightforward understanding, land areas with steeper slopes have more surface area exposed to rainfall than areas with shallower slopes assuming identical rainfall direction and intensity. The additional surface area allows more infiltration and causes less surface runoff, which potentially reduced the risk for debris flow.

3.8 Landslides

Landslides occur on steep slopes of "loose" soil or rock material, though steep slopes can be "stable" over long periods of time. Here, plants hold the soil and rock material in place with their roots and transpire excess soil water that could otherwise cause positive pore water pressures. An intense storm event or change in vegetation or drainage conditions can cause the slope material to become unstable and to move downhill as a landslide. Depending on the processes involved, slope movement can happen slowly ("creeping slopes") or rapidly, negatively impacting downhill areas.

Landslides can be triggered by a wildfire due to the loss of live vegetation, particularly the loss of a mechanically stabilizing root system and the decrease in transpiration, both resulting in higher soil water content and lower soil strength. Higher pore water pressure in the wetter soil decreases the effective stress and shear strength within the slope, which eventually causes a ground failure resulting in a landslide. For wet soil close to water saturation, positive pore water pressures can occur and solid material from slopes start to creep or even flow (see also debris flow), depending on water content and soil texture.

4. TOOLS TO ASSESS AND PREDICT WILDFIRE EFFECTS ON WATERSHED HYDROLOGIC PROCESSES

4.1 General

The U.S. Department of Agriculture (USDA) Forest Service Burned Area Emergency Rehabilitation (BAER) Teams evaluate fire effects on soils and watersheds onsite to determine if a fire created emergency watershed conditions (Davis and Holbeck, 2001). If emergency watershed conditions are found, BAER teams map and describe magnitude and scope of the emergency, identify values at risk and develop treatment prescriptions to protect the values at risk. Mitigation or warning of the public of potential adverse fire effects to soil productivity and watershed response are the goals of the BAER team watershed assessment. However, the assessment typically does not provide quantitative information on expected post-fire peak flow or sediment yield. For more details on BAER soil and watershed assessment, refer to Davis and Holbeck (2001) and Neary *et al.* (2005).

4.2 Flooding

The key question with respect to the flooding issue is: *how much more peak flow could be expected so that effective flood control measures can be taken in or downstream of a fire-affected watershed*? As outlined in the subsequent paragraphs, several studies were already carried out to quantify fire effects on soil and the hydrologic response of a watershed, especially regarding changes in peak flow as a measure for flood control. The general goal of these studies was to use available methodologies or watershed hydrology models and simulate fire effects on surface runoff and stream flow by adjusting the values of (potentially) fire-sensitive input parameters like surface coverage, surface roughness, soil hydraulic conductivity, etc.

4.2.1 Empirical Approaches

The USDA Forest Service, presented the first quantitative estimates to predict the effect of fire on peak discharge and erosion rates for 256 individual forested watersheds in southern California (USDA, 1949), and to assess and predict of the amount of damage, both actua1 and potential, caused by increased flood and erosion as a result of fire. Determining the effects of complete burning of the watershed vegetative cover on peak discharge was made by comparing (1) peak discharge rates of burned watersheds with those of similar but unburned watersheds for the same storm, or (2) peak discharge rates from similar storms on the same watershed before and after burning. From these two approaches, a series of curves showing the average effects of complete burning on normal peak discharge by years after burn were developed.

More recently, the Hydrology Manual by the Los Angeles County Department of Public Works (LACDPW, 1991a) suggested a simple model, the Modified Rational Method (MODRAT), to consider fire-effects on rainfall-runoff relationships for the clear water discharge Q (cfs)

$$Q = C \times I \times A \qquad (2)$$

where I is the rainfall intensity at a given point in time (in/hr); A is the watershed area (acres); and C is the dimensionless runoff coefficient, which depends on rainfall intensity, soil type, and the degree of development and burn severity of a watershed. To consider the effect of sediment load on total ("bulked") discharge Q_B (cfs), the Sedimentation Manual by the Los Angeles County Department of Public Works (LACDPW, 1991b) gives bulking factors, $BF_{(A)}$, to be multiplied with the clear water discharge Q (cfs)

$$Q_B = BF_A \times Q \tag{3}$$

For details on the procedure to calculate Q and Q_B, refer to LACDPW (1991a,b).

As a reaction to the October 2003 fires in southern California, the Federal Emergency Management Agency (FEMA) issued a report on hydrologic and hydraulic methodologies used to estimate post-burn floodplain hazards (FEMA, 2003). The report suggested using correction factors for the pre-burn discharge as a quick estimate for post-fire peak flows with various frequencies. Based on pre-burn discharge $Q_{regression}$ calculated with the California Regional Regression Equations, available through the National Flood Frequency (NFF) program web site (http://water.usgs.gov/osw/programs/nffp.html), FEMA (2003) modeled the post-burn discharge $Q_{post\text{-}burn}$ as

$$Q_{post-burn} = Q_{regression} \times C_{caf} \times C_{baf} \tag{4}$$

where C_{caf} is the clear water adjustment factor, and C_{baf} is the bulking adjustment factor. C_{caf} takes the clear water increase from the fire into account and is calculated based on a pre- and post-fire SCS Curve Number Loss analysis (for details regarding SCS Curve Number Loss model, see e.g., USACE, 2000). The C_{baf} factor considers that the total post-fire discharge can considerably increase by the sediment transported by water flow ("bulking").

4.2.2 Semi-empirical and Process-oriented Approaches

The models presented so far are geared toward simple and fast ("black box") rainfall-runoff predictions. More recently, case studies were carried out to validate some available hydrology models on fire-affected watersheds. Earles *et al.* (2004) used the SCS Curve Number Loss model (USDA-SCS, 1972) to predict the impact of the May 2000 Cerro Grande Fire near Los Alamos, New Mexico, on the hydrologic properties of watersheds around the Los Alamos National Laboratory. They found that a first prediction of precipitation excess using curve numbers (CN) derived from the literature underestimated peak flows observed from a storm event following the wildfire. By adjusting curve number values for various combinations of burn severity and soil hydrophobicity, reasonable agreement between available data and model results was achieved (Earles *et al.*, 2004).

Canfield and Goodrich (2005) proposed to use the Automated Geospatial Watershed Assessment (AGWA) tool (www.tucson.ars.ag.gov/agwa) to assess wildfire effects on watershed hydrology. As a GIS-based model, AGWA uses readily available spatial data sets to perform watershed hydrologic analysis using the empirical Soil & Water Assessment Tool

(SWAT) (Arnold *et al.*, 1994; www.brc.tamus.edu/swat) and process-based KINematic Runoff and EROSion Model 2 (KINEROS2) (Smith *et al.*, 2005; www.tucson.ars.ag.gov/kineros) hydrological models. The Soil & Water Assessment Tool is a continuous-simulation model for use in large (river-basin scale) watersheds based also on the SCS Curve Number Loss model. The KINEROS2 model is event-driven, developed for small (<100 km^2) arid, semi-arid, and urban watersheds. Similar to Earles *et al.* (2004), Canfield and Goodrich (2005) suggest taking fire effects into account by adjusting input parameters of their hydrology model. They illustrate the use of AGWA-SWAT for fire-affected watersheds on a data set collected from the 2003 Aspen Fire near Tucson, Arizona. A relationship between soil surface cover and CN was derived, which provided a basis to estimate fire-induced changes in CN from burn severity maps. Canfield and Goodrich (2005) found that their estimated changes in CN are smaller than the values derived from experience using, for example, post-fire BAER analyses. Post-fire runoff calculations using estimated CN values showed a good agreement with measured total runoff value. Measured and calculated, fire-induced changes in total runoff volume were rather small compared to the considerable changes in post-fire peak runoff. Therefore, Canfield and Goodrich (2005) concluded that peak flow prediction is not sensitive to CN values. From their analysis, however, they found that peak flow is most sensitive to hillslope roughness. Simulation of observed post-fire storm events from the Starmer Canyon data set at Los Alamos National Laboratory employing KINEROS2 showed that “best-fit” post-fire hillslope roughness is similar to values for bare soil conditions immediately after the fire. Roughness increased to values typical for forested areas after the soil surface cover underwent a three-year recovery period. Canfield and Goodrich (2005) also compared data available from a watershed at the Marshall Gulch station (830-ha drainage area, Pima County, Arizona) from 1951 to 1959, with data collected after the Aspen Fire and found that the ratio between peak and average discharge increased from 3.6 to 4.9 (Figure 8).

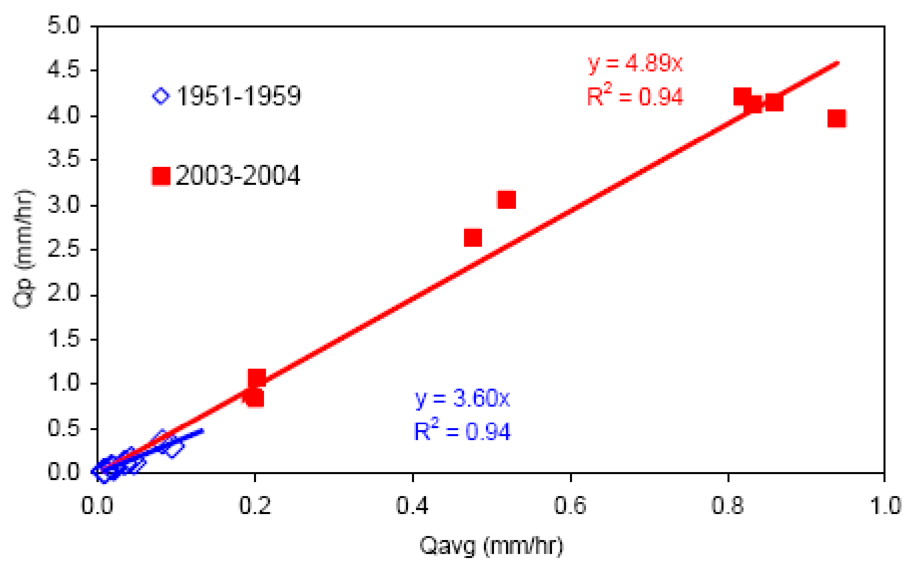

Figure 8. Peak versus average discharge before and after the Aspen fire at the Marshall Gulch station (taken from Canfield and Goodrich, 2005).

Guardiola-Claramonte (2005) applied the distributed watershed model MIKE SHE to study potential effects of the 2003 Aspen wildfire on the hydrologic response of the Sabino Creek basin, in Arizona. The MIKE SHE model (Refsgaard and Storm, 1995) is a distributed, grid-based modeling system allowing the simulation of all major hydrologic processes occurring in the land phase of the hydrological cycle. Guardiola-Claramonte (2005) focused on a model sensitivity study to evaluate whether predicted changes in catchment response are similar to those observed. Of particular interest were the catchment responses to changes in hydraulic conductivity of the near-surface soil and the removal of vegetation. The model allows for varying of surface conditions locally. It was calibrated and validated based on field observations and meteorological data for more than nine years and a set of fire-effect scenarios were run. Guardiola-Claramonte (2005) found:

- Although an increase in overland flow is observed after the fire, the total volume that this overland flow represents is small. There was, however, a lack of observations of overland flow with which model simulations could be verified.

- Overland flow is exclusively due to the presence of the hydrophobic layer. The increase in overland flow after the fire is more important in the high burn severity zones. However, as mentioned before, the volume of overland flow is negligible compared to the volume of water that infiltrates, which may be a shortcoming of the model setup.

- The scenario analysis shows a slight increase (5 percent) in infiltration after the fire, because less precipitation is intercepted by the forest canopy and less water is evaporated, raising the soil water content.

- The effects of fire on stream flow are mainly due to the reduction of the vegetation, rather than the presence of soil hydrophobicity.

- The loss in vegetation is responsible for a decrease in the number of low flow events (less than 0.10 m^3/s), and an increase in the mid (0.10 to 12 m^3/s) and high (12 to 90 m^3/s) stream flow events.

- The presence of a hydrophobic layer slightly affects the mid flows and high flows, but significantly increases the number of extreme flow events.

- The importance of the hydrophobic layer increases when increasing the degree of hydrophobicity.

- The reduction in evaporation, due to the loss in vegetation, increases the volumetric water content in the watershed by about 5 percent.

The studies by Earles *et al.* (2004), Canfield and Goodrich (2005), and Guardiola-Claramonte (2005) show that “standard” watershed hydrology models, using modified input parameters, initial and boundary conditions to account for fire effects, can simulate post-fire effects on watershed hydrology. The above-described CN approach is relatively simple and widely used by hydrologists and engineers. With the SCS model, CN changes due to fire effects can be determined by analyzing a watershed before and after the fire. If no pre-fire data are available, data from similar watersheds nearby or information from previous studies on similar watersheds can be used. Although useful to predict changes in base flow, CNs fail to predict changes in peak flow. As shown by Canfield *et al.* (2005), post-fire peak flow can increase by about one order of magnitude without a significant change in CNs, although peak flow was more sensitive to surface roughness. Given the large variability in soils, vegetation and fire characteristics, an improved understanding of the underlying fire-hydrology processes is necessary to better predict effects of fire on flow rates and volumes. This would help, for example, to understand the physical processes that control the change in peak to average discharge ratio as shown in Figure 8 and how they change after fires by analyzing fire-affected watersheds with studies similar to Canfield and Goodrich (2005) and Guardiola-Claramonte (2005).

4.3 Soil Erosion and Sediment Yield

Related to soil loss, limited revegetation potential, increase in sediment load, and the related increased risk for flooding after a wildfire, is the second question: *how much more soil erosion and sediment yield should be expected in a fire-affected watershed*?

Because sediment yield from a watershed is relatively easy to determine by tracking the amount of sediment annually excavated from sediment retention basins, information on erosion rates has been available for some time. The USDA (1949) determined the effects of complete burning on the average annual erosion rates of individual 256 individual watersheds in southern California by comparing erosion rates of burned watersheds with those of similar unburned watersheds. The weighted average ratios between normal annual erosion rates and the annual erosion rates following burning were computed. These ratios, corrected for variation in proportion to burnable areas, were used to calculate probable erosion rates of the individual watersheds by years from time of burning until return to normal. Effects of partial burning of the watershed on erosion rates were assumed to be proportional to the area burned.

The Sedimentation Manual by the Los Angeles County Department of Public Works (LACDPW, 1991b) provides a model to estimate fire-effects on sediment yield (or debris production) of a watershed. According to LACDPW (1991b), debris production (DP) (yd^3) is calculated as

$$DP = DPR \times A \tag{5}$$

where DPR is the debris production rate (yd^3/mi^2) and A is the watershed area (mi^2). Debris production rates have to be determined from debris potential areas (DPA) mapped for the individual watersheds (for details see LACDPW, 1991b). The advantage of this sediment yield model is its simplicity. It needs, however, watershed-specific information that has to be mapped first.

To be capable of tackling fire effects for a particular watershed with unknown debris potential, erosion models with the capability to capture changes in net precipitation, surface coverage (litter, duff, live vegetation), surface runoff, and “soil erodibility” (soil structure, texture, cohesion) have to be applied. Depending on the model, these parameters are either incorporated into empirical factors, as done in the Water Yield and Sediment Model (WATSED), the Universal Soil Loss Equation (USLE), and, more recently, the Revised USLE (RUSLE), or related to physical processes (KINEROS2, Water Erosion Prediction Project [WEPP]). WATSED, USLE/RUSLE and WEPP were developed to predict soil loss due to erosion from agricultural fields and forested areas (USDA, 1990; Renard *et al.*, 1997; Ryan and Elliot, 2005). WEPP (Flanagan and Livingston, 1995) provides a complex physically-based model that simulates soil erosion by modeling the processes that cause erosion. These processes include daily plant growth, residue accumulation and decomposition, and daily soil water balance. Each day with a precipitation or snow melt event, WEPP calculates the infiltration, runoff, and sediment detachment, transport, deposition, and yield. WEPP has a watershed version under development, but it has received little use outside of research applications (Ryan and Elliot, 2005). KINEROS2, as part of the AGWA tool (Canfield and Goodrich, 2005) considers soil erosion processes similar to WEPP. As an example, WEPP and KINEROS2 model the amount of eroded soil material as a function of the shear stress exerted by surface runoff and shear strength of the underlying soil. It is expected that net precipitation, surface runoff, and soil erodibility all increase and surface coverage of vegetation will decrease after a fire. These factors all lead to a general increase in erosion, although in some cases not immediately after the fire (Cerdà and Doerr, 2005; Cerdà and Lasanta, 2005).

4.3 Debris Flow

Related to increased risk of flooding and erosion, the third important question is: *what is the additional debris quantities and sizes one can expect in or downstream of a fire-affected watershed*? After analyzing numerous storm and subsequent debris flow events in wildfire-affected watersheds in southern California, USACE (1992) proposed using a model that incorporates empirical "fire factors" (FF), which considers the effect of wildfires on debris yield due to single storm events. Although created as a method for designing sediment/debris basins, it can be used to estimate debris yields from single storm events. The USACE (1992) found by regression analysis that, in addition to the effects of wildfires, debris yield is strongly affected by peak precipitation (for watersheds less than 3.0 mi^2), surface runoff (for watersheds greater than 3.0 mi^2), and the amount of debris available within the watershed ("storage of potential debris"). For small watersheds (0.1 to 3.0 mi^2), USACE (1992) proposed

$$\log(D_y) = 0.65\log(P) + 0.62\log(RR) + 0.18\log(A) + 0.12FF \qquad (6)$$

where D_y is the unit debris yield, P is the maximum one-hour precipitation rate, RR is the relief ratio, A is the drainage area, and FF is the fire factor (Figure 9). For larger watersheds (greater than 3.0 mi^2), formulas similar to Equation (1) were found with different weighting factors for different watershed sizes and surface runoff instead of maximum precipitation as the key meteorological parameter (USACE, 1992). Fire factors were found to decrease nonlinearly with increasing time after a wildfire (Figure 9).

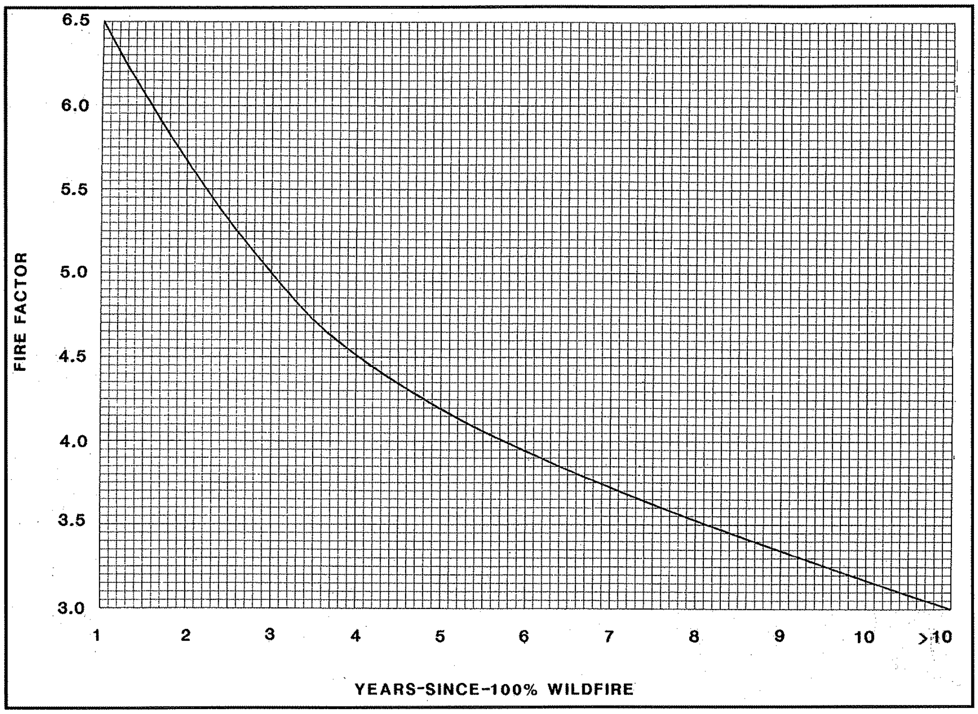

Figure 9. Fire factor curve for watersheds of 0.1 to 3.0 mi^2 (taken from USACE, 1992).

As Figure 9 shows, wildfires have a decreasing impact on debris flow with increasing time after the fire event. Figure 9 also indicates that wildfire effects on debris yield could be detected after more than 10 years, in contrast to the majority of the changes in hydraulic properties (hydraulic conductivity, water repellency, etc.) reported in the literature, which tend to return to original values more quickly (see also Chapter 5). “Full recovery” for a watershed depends on the vegetation present before the wildfire. Larger, older trees take much longer to grow back than smaller shrubs, bushes, and grasses.

4.4 Landslides

With respect to landslides the critical questions are: (a) where are unstable slopes located in a fire-affected watershed, and (b) can the size of potential landslides be predicted? The basic processes and means to analyze slope stability problems have been known for a long time (Terzaghi, 1943; Terzaghi and Peck, 1948), and the onset of a landslide also has been the subject of numerous studies, because of the significant loss of property and human lives involved. More recently, Discrete Element Modeling (Cundall and Strack, 1979) and advanced continuum mechanics approaches (e.g., Porous Media Theory [de Boer, 2000]) allow engineers to analyze not just the onset, but also the evolution of landslides and how they interact with the environment, like precipitation and “bio-reinforcements” (plant roots). Most of the available models are in a rather experimental state and validation is just underway. Until now, however, landslides cannot be analyzed in simplified terms or as part of a hydrology model.

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5. PERSISTANCE OF FIRE EFFECTS ON WATERSHED HYDROLOGIC PROCESSES

5.1 What is Known about the Persistence of Fire Effects on Watershed Hydrologic Properties?

An important question regarding fire effects is how long do effects on watershed hydraulic properties remain after an individual wildfire? The current study mainly focused on fire effects on soil hydraulic properties, aware of the fact that recovery of vegetation plays an important role for recovery of the entire watershed. As indicated by long-term experimental findings used for debris yield estimates (USACE, 1992), fire effects may persist for more than 10 years. Reeder and Jurgensen (1979) and Giovannini *et al.* (1987) showed that hydrophobicity of soils can persist anywhere from one to six years after a fire and decrease over time as the soil recovers from the effects of the fire. Robichaud (2000) stated that hydrophobicity in soils is broken up or is sufficiently washed away within one to two years after the wildfire. A detailed study by Pierson *et al.* (2001) on larger test plots (greater than 250 m^2) on a wildfire-affected hillslope in northwestern Nevada showed that fires did not significantly impact the average infiltration rates on the hillslopes, in general, and in the interspace microsites, in particular (Figure 10). In the study, the plots were subdivided into 10 microsites of either coppice (under shrub canopy) or interspace (area between shrubs dominated by grass and forbs) for which infiltration, surface runoff, and erosion rates were determined. Infiltration rates in the coppice area decreased significantly immediately after the fire but “recuperated” within one year. This finding is particularly interesting because, within the same time period, water repellency decreased but was still significantly higher for the burned microsites compared to the unburned microsites. The study also indicated that the “natural” difference in infiltration capacity between coppice and interspace areas might be larger than between burned and unburned coppice and interspace areas, respectively. For example, the unburned interspace microsites in 1999 had the lowest infiltration rates of all sites and plots (Figure 10B). Pierson *et al.* (2001) concluded that:

- Fire-induced water repellency does reduce water infiltration. The effects, however, were short term and small in magnitude. As important as fire-induced water repellency seems to be, the lack of vegetation and litter appears to be equally important.

- Temporal variations in infiltration rate and associated soil and vegetation properties are important factors to consider. Temporal variations in infiltration rates between years for all burned and unburned sites were greater than the spatial variations caused by the fire.

Table 1 summarizes results from some additional studies on how rapidly soil parameters and watershed hydraulic properties recover from a single fire event. It is interesting to note that the soil hydrology related parameters recuperate within a very short time period, whereas long-term effects are mainly seen in erosion and debris yield.

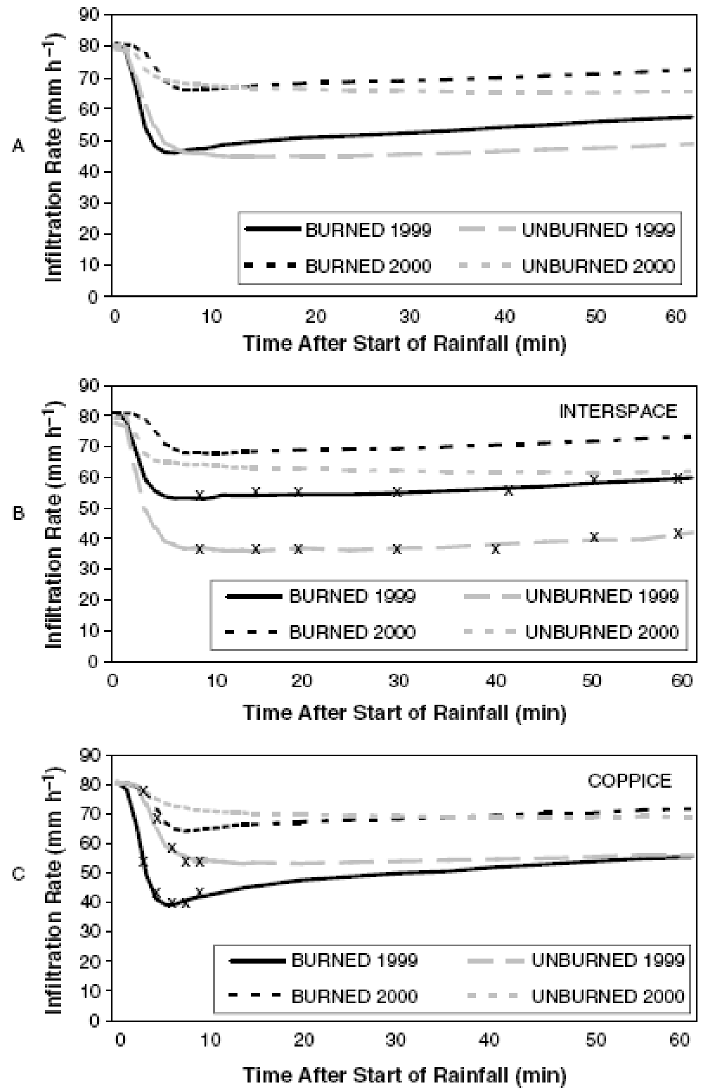

Figure 10. Average infiltration rate over time for entire plots (A), interspace microsites (B), and coppice microsites (C) on burned and unburned hill slopes immediately after (1999) and one year post-wildfire (2000) (taken from Pierson *et al.*, 2001).

Table 1. Persistency of fire effects with respect to parameters like water repellency (WR), infiltration rate (IR), K_{sat}, surface runoff (SR), erosion (E), and debris yield (DY). (NIA: no information available.)

Reference	Parameters	Time frame covered (years)	Effects found for (year)	No effect after (years)	Scale observed (m)
(USACE, 1992)	DY	>10	>10	NIA	NIA
(DeBano, 2000)	WR	NIA	<6	NIA	NIA
(Robichaud, 2000)	WR, K_{sat}	2	1	2	1×1
(Pierson *et al.*, 2001)	IR	2	1	1	> 250 m^2
(Cerdà and Doerr, 2005)	SR, E	11	2 (under grass & shrubs) 10 (under trees)	2 (under grass & shrubs)	NIA
(Cerdà and Lasanta, 2005)	SR, E	NIA	Plot1: 2; Plot2: 7	Plot1: 3; Plot2: >7	3×10
(Canfield and Goodrich, 2005)	K_{sat}	3	3	NIA	NIA
(Hubbert *et al.*, 2006)	WR	76 days	7 days	76 days	0.15×0.15 m up to 1.28 ha

Except for the effects reported by DeBano (2000), none of the references indicate that fire effects on infiltration, especially water repellency, lasted longer than three years. On the other hand, the most intensive surface runoff and erosion were reported not immediately after the fire, but in the subsequent couple of years, as indicated by several authors (Wilson, 1999; Pierson *et al.*, 2001; Cerdà and Doerr, 2005; Cerdà and Lasanta, 2005). This might be due to deterioration of the soil surface structure initiated by the fire, the occurrence of storm events that expose aggregates to direct raindrop impact, and the distance from the burn area where effects are being noted. These impacts turn the aggregates into a slurry of finer particles, which either leads to the formation of a surface crust or enhances erosion away from the site if enough surface runoff occurs. An interesting insight into the importance of post-fire revegetation is given by Pierson *et al.* (2001) and Cerdà and Doerr (2005), who stated that the key to understanding soil recovery after a wildfire is how quickly the bare soil can be covered again by vegetation or litter. Surface runoff was reduced most rapidly under herbs, followed by shrubs and trees (Cerdà and Doerr, 2005). This might also explain why recovery takes longer in arid than in humid environments, as revegetation in arid environments is slower and bare soil between shrubs and trees is typical. In areas where vegetation or other forms of surface cover do not recover fast enough, a permanent surface crusting or complete soil loss due to erosion can occur. Eventually, different recovery times might also be due to different definitions of recovery in terms of infiltration recovery, return to stable erosion yield, vegetation recovery, etc.

The easiest way to identify the important processes that govern the response of a specific watershed to a wildfire is to:

- Run a sensitivity analysis using an event model suitable for the watershed,

- Adjust the input parameters, initial and boundary conditions (e.g., net precipitation, surface cover, infiltration capacity) to account for fire effects based on a best practice, and

- Evaluate the changes of hydrologic/hydraulic response of the watershed using field-based monitoring.

To conduct a sensitivity analysis, one simulation is needed for the first year after the fire and again for the second or third year after the fire. The advantage of such a sensitivity analysis is also the capability to account for the timing and sequence of storm events. The hydrologic response of a fire-affected watershed from a major storm can be completely different if the storm hits the watershed immediately after the fire, where the bare soil surface is exposed, or several years later when revegetation can buffer the precipitation and increase infiltration capacity.

5.2 Suggested "Recovery Function" for Soil Hydraulic Conductivity after a Wildfire

For a watershed where infiltration is the key process that governs the watershed hydrologic response to a wildfire, an infiltration recovery function can be postulated using, for example, the Green-Ampt (Green and Ampt, 1911) infiltration model, adjusting hydraulic conductivity in the model as a function of time after the fire. The Green-Ampt infiltration model as briefly introduced in the subsequent section describes one-dimensional infiltration into a homogeneous soil with horizontal surface and surface pressure head $H_0 = 0$

$$\frac{dI}{dt} = K\left[1 - \frac{(\phi - \theta_i)}{I} S_f\right] \qquad (7)$$

where I (m) is cumulative infiltration at time t, dI/dt (ms^{-1}) is the infiltration rate, K (m s^{-1}) is the saturated hydraulic conductivity between ground surface and the wetting front, ϕ (-) is the soil porosity, θ_i (m^{3}m^{-3}) is the initial soil volumetric water content, and S_f (m) is the pressure head at the wetting front (notation according to Hillel [1998]). Equation (7) reflects how the infiltration rate depends on the physical and hydraulic properties of the soil. A wildfire will affect these soil parameters, especially close to ground surface where deterioration of soil structure decreases porosity and hydraulic conductivity, and where soil water content remains higher. For subsoil horizons (E, B, and C in Figure 2), wildfires can change water repellency and, therefore, hydraulic conductivity, although the wildfire has little impact on porosity. From the parameters in Equation (7), only ϕ and K are material properties and, therefore, are potentially affected by long-term alteration of the soil due to weathering or structural deterioration. Because the potential range of ϕ given for different soil textures is already rather narrow, porosity might not be very sensitive to wildfires. Saturated hydraulic conductivity, however, can easily change over several orders of magnitude and is, together with S_f for dry soils, probably the most sensitive parameters affecting estimates of infiltration rate. Assuming that (a) K_{sat} is the key parameter affected most by wildfire, and (b) that the change in K_{sat} immediately after the fire can be estimated by using Equation (1) according to Robichaud (2000) assuming that water repellency is the key factor that changes infiltration capacity.

Using the recovery time values from Table 1 as a guideline, time for full recovery can be estimated and a hydraulic conductivity recovery function K_{rec} can be proposed as

$$\begin{gathered} K_{rec}(t < t_0) = K_{sat} \\ K_{rec}(t_0 \leq t \leq 2 years) = K_{hydrophobic}(t) \\ K_{rec}(t > 2 years) = K_{sat} \end{gathered} \tag{8}$$

where t_0 is the moment the fire occurs. Whether $K_{hydrophobic}$ is linear, logarithmic, or some other function is uncertain. At this stage, the actual form of $K_{hydrophobic}(t)$ is probably less important if $t - t_0$ is small (less than 2 years).

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6. CONCLUSIONS AND RECOMMENDATIONS

From a hydrologic point of view, the following wildfire effects are important:

- Loss of vegetation and soil surface cover decreases interception and allows more precipitation to reach the mineral soil surface. This increased net precipitation may more quickly exceed soil infiltration capacity and enhance surface runoff. Loss of live vegetation also decreases transpiration and can increase soil water content assuming similar precipitation amount and intensity.

- Decrease in infiltration capacity can occur due to loss of soil surface cover, surface crusting or formation of a water-repellent layer. Decrease in infiltration capacity can cause surface runoff responsible for higher water peak flow, faster times to peak, and debris flow, as well as soil surface erosion and landslides.

- Higher peak flows and potential risk for flooding due to increase in net precipitation, decrease in infiltration capacity, and subsequent increase in surface runoff and sediment transport (bulking).

- Increase in soil erosion and sediment yield due to loss of soil surface cover, soil structure deterioration, and surface runoff.

- Increase in debris flow due to surface runoff and increased sediment yield due to erosion and landslides.

- Decrease in slope stability and increasing probability for landslides due to loss of stabilizing vegetation and increase in soil water content.

The effects of decreased interception and infiltration capacity on the hydrologic response of a watershed vary depending on the (a) portion of the watershed affected by the fire, (b) severity of the fire in the respective areas, and (c) timing, intensity, and duration of the first storm after the fire and subsequent storms. For example, a severely burned watershed might respond with little increase in peak flow, debris flow, or erosion if, after the fire, no intensive storm event occurs before the soil has been revegetated and other short-term fire effects have dissipated.

The effects of fire on soil hydraulic properties, particularly the processes of water-repellent layer formation, are fairly well understood conceptually and can be measured and modeled at the laboratory and small test plot scales in the field (for details, see e.g., DeBano, 2000). A variety of approaches are already available to assess and predict wildfire effects on watershed hydrology, particularly base and peak flow in streams and sediment yield, ranging from empirically based (USDA, BEAR) to semi-empirical (MODRAT, FEMA, SCS_CN, SWAT), and process-oriented models like KINEROS2 and MIKE SHE. Case studies by Earles *et al.* (2004), Canfield and Goodrich (2005), and Guardiola-Claramonte (2005) show that "standard" watershed hydrology models, using modified input parameters, initial and boundary conditions to account for fire effects, can simulate observed post-fire effects on watershed hydrology.

Reversible fire effects like temporal loss of vegetation and surface cover, soil surface crusting, and water-repellent layers last between weeks and years, depending on climate conditions, fire severity, vegetation, and soil type. Potentially irreversible changes occur if soil surface crusting suppresses seed germination, and the soil is permanently lost due to erosion, or invasive species replace native plant species.

To assess and predict wildfire effects on watershed hydrologic processes, it is recommended to use currently available modeling frameworks that deal with hydrology on the watershed scale (e.g., SCS-CN [Earles *et al.* 2004], AGWA [Canfield and Goodrich, 2005] or MIKE SHE [Guardiola-Claramonte, 2005]), adjust individual hydrologic processes to account for fire effects, and correlate effects to surface runoff and subsequent peak- and baseflow changes in streams, and sediment yield within a watershed.

For further improved modeling of wildfire effects on watershed hydrology, there are needs for (a) quick and reliable methods to determine fire-induced changes in soil hydraulic properties, (b) a better model of water infiltration into multi-layer soils, and (c) improved schemes to scale-up soil hydraulic properties from observation scales to the watershed scales.

7. FUTURE RESEARCH

7.1 Infiltration Measurements

Field infiltration experiments can provide parameters for soil hydraulic properties. To date, a paucity of manuscripts and other communications are available that describe the direct measurements of soil hydraulic properties of post-fire soils. The absence of physical characteristic data for post-fire soil hampers our understanding of wildfire impacts on hydrological processes; thus, field experiments would provide a useful information dataset, both for general understanding of impacts of fire but also for examining analytical and numerical approaches for predicting impacts of fire.

Rainfall simulators and infiltrometers are perhaps the most commonly used instruments for measuring surface runoff and infiltration. Rainfall simulators are mainly designed for studies of soil erosion but can also be used for studying infiltration. To obtain the soil hydraulic properties, either the runoff at the outlet of an experimental plot or the time to initial abstraction is measured. The infiltration parameters are then solved using the difference between applied rainfall and the runoff. It is now more common to apply the rainfall simulator to check predictions based on soil hydraulic properties obtained from other approaches.

Infiltrometers are more widely used for field measurement of soil hydraulic properties. The most popular infiltrometer is the surface disk tension infiltrometer. This infiltrometer maintains a constant negative water head on the soil surface, and the water entry rate is measured using water level decreases in a reservoir. By applying a series of negative water pressures during an experiment, and measuring the water entry rate, the soil hydraulic parameters can be back-calculated by fitting the entire infiltration curve. The infiltrometer uses less water in the experiment than the rainfall simulator and is more efficient and capable of providing the soil retention curve and conductivity curves. Disk infiltrometers are highly portable, and thus can be taken to remote areas for measurements that take 1 to 2 hours.

7.2 Models to Simulate Multi-layer Profiles

Building on already implemented, physically based infiltration models by Green and Ampt (1911) and Parlange *et al.* (1982), a multi-layer soil model that captures changes in soil hydraulic properties from loss of litter and duff, surface crusting, or water repellency is highly recommended, especially since the post-fire soil features a multi-layer profile considerably different from the pre-fire profile. The soil profile after a wildfire event will usually contain two to three fire-induced layers: the ashy layer (not necessarily visible) near the top of the water-repellent layer and an underlying layer of wettable soil.

Infiltration into such a soil profile is similar to water movement through a fine-textured soil with a middle layer of coarse-textured soil. In this situation, the wetting front moves rapidly through the wettable layer until it reaches the water-repellent layer, after which the infiltration rate drops to that of the water-repellent soil. The infiltration rate remains depressed until the wetting front passes through the water-repellent layer into the underlying wettable soil; then the rate again begins to increase (DeBano, 2000). Recent evidence shows that the top layer of ash acts as a storage reservoir of rainfall (Martin and Moody, 2001; Woods and Balfour, 2006). Runoff will not be generated until the storage capacity of this layer is exceeded. This is contrary to the traditional ash-sealing hypothesis, in which the ash penetrates into soil pores and causes soil sealing and reduced infiltration rate.

A conceptual model for water movement into layered soil after wildfire events is presented here as a possible solution to this problem. Considering pronounced layered structures for fire-burned soil (Figure 3), the following infiltration mechanism for each layer can be assumed:

- The top layer of ash acts as a water storage reservoir, storing rainfall until it is fully saturated.
- Infiltration in the water-repellent layer below the ash layer can be described by the Green-Ampt model, with the wetting front suction specified as a small positive value or a negative value.
- Infiltration in the underlying wettable soil can be calculated with the general three-parameter infiltration model (Parlange *et al.*, 1982; Smith *et al.*, 1993, 2002)

Based on the above assumption, the following three-layer infiltration model is proposed:

In the top ashy layer

$$f_1 = r \text{ for } S_t \le S_c = Z_1\left(\theta_{s1} - \theta_{i1}\right) \tag{9}$$

In the water-repellent layer

$$f_2 = K_{s2}\frac{H_2 + G_2 + L_2}{L_2} \tag{10}$$

$$f_2 = \frac{dI_2}{dt} = \left(\theta_{2s} - \theta_{2i}\right)\frac{dL_2}{dt} \tag{11}$$

In the wettable bottom layer

$$I_3 = \frac{\left(\theta_{s3} - \theta_{i3}\right)\left(G_3 + H_3\right)}{\gamma}\ln\left[1 + \frac{\gamma K_{s3}}{f_3 - K_{s3}}\right] \tag{12}$$

$$f_3 = \frac{dI_3}{dt} = \left(\theta_{3s} - \theta_{3i}\right)\frac{dL_3}{dt} \tag{13}$$

where subscript 1 is for variables in layer 1 (the ashy layer), 2 is for layer 2 (the water-repellent layer) and 3 is for layer 3 (the bottom wettable layer), r is the rainfall intensity, S_c is the storage capacity in layer 1, S_t is the actual storage, f is the infiltration rate; $I = L(\theta_s\text{-}\theta_i)$ is the infiltration depth, where L is the distance between the wetting front and the top of the corresponding layer, θ_s is saturated water content, θ_i is the initial water content; K_s is saturated hydraulic conductivity; *G* is averaged capillary pressure head across the wetting front; *H* is the pressure head at the top of each layer; and γ is a parameter related to soil hydraulic properties, and is equal to 0.8 to 0.85 for most mineral soils (Smith *et al.*, 2002). The infiltration rate can be obtained by solving these equations with the evolution of the wetting front with depth.

Besides a better model to capture water infiltration, a quantitative model to estimate the ratio between net and total precipitation after a wildfire is necessary. The "First Order Fire Effect Model" (FOFEM), developed by the USDA Forest Service, with its predictions on soil heating, fuel consumption, and tree mortality, could provide a first step toward estimating post-fire surface cover.

7.3 Schemes to Scale-up from Individual Plot to Watershed-scale Soil Hydraulic Properties

Modeling fire-induced changes in hydrologic processes at the watershed-scale based on measured "point"-information remains a challenge. This is mainly due to (1) highly heterogeneous infiltration behavior of the unaffected soil *per se* ("preferential flow versus homogeneous Darcy- and Richards-type infiltration [Ritsema and Dekker, 1994, 2000; Ritsema, 1998]), (2) very wide spatial and temporal distribution of the actual burned sites ("hot spots" close to almost unburned soil), and (3) complex topography that leads to local surface runoff and ponding. The studies by Pierson *et al.* (2001) and Rau *et al.* (2005) provide some first quantitative information about spatial and temporal variability of fire effects on soil hydraulic properties. Some of these issues have already been addressed in models like KINEROS2 and MIKE SHE, but improved upscaling schemes are necessary to optimize the amount of measured point-information for reliable watershed-scale assessment and prediction.

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