

# Sprague River CEAP Study Report



**USDA Natural Resources Conservation Service  
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## Executive Summary

Nationally, the United States Department of Agriculture (USDA) initiated the Conservation Effects Assessment Project (CEAP) in 2003 to better document the effects of conservation practices on private lands that are often funded through federal cost-share programs (e.g. the Environmental Quality Incentives Program, the Wetland Reserve Program, the Conservation Reserve Program, and others). The Sprague River Watershed, located in the Klamath Basin, was nominated by the Natural Resources Conservation Service (NRCS) in 2004 for a special CEAP study due to its prominence in water and endangered species issues in the area.

The Sprague River CEAP study was designed to provide information about conservation practices through field monitoring and computer model simulations of the hydrologic budget. The Danish Hydrologic Institute's MIKE SHE hydrologic model<sup>1</sup> was selected as the most appropriate hydrologic software. The MIKE SHE, an integrated hydrological modeling system, covers the entire land phase of the hydrological cycle, linking surface runoff with channel hydraulics and ground water hydrology.

Prior to the beginning of this study, millions of federal cost-share dollars were spent in the Upper Klamath Basin improving irrigation systems and their management, clearing Western juniper, restoring wetlands and riparian areas, and thinning overstocked forests. The effects of these activities in the Sprague River Watershed should be similar to the effects that conservation efforts would induce in other areas in the semi-arid western United States.

This study focused primarily on the effects of irrigation. Field data were collected to calibrate and verify the MIKE SHE hydrologic model. Irrigation alternatives were formulated for individual fields and a sub-watershed to answer scale appropriate questions. The field scale also was used to answer questions about the efficiency of various irrigation and management systems. The sub-watershed scale provided the backdrop to understanding the movement and timing of surface and subsurface irrigation return flows to the river. The amount and timing of return flows were thought to be critical to the availability of water for fish and wildlife and the use of water by downstream irrigators, as well as for understanding the impacts on water quality.

In general, the study found that converting from wild flood to more efficient irrigation systems and management resulted in:

- Reduced surface and subsurface irrigation return flows to the river.
- Lowered summer base flows in the river.
- Decreased annual water yield from the watershed
- Increased plant evapotranspiration and, consequently, production.
- Improved water quality (less delivery of nutrients and warm water to the river).
- Lowered summer base flows and annual water yield if ground water pumping for irrigation were reduced.

The potential effects from juniper removal, forest thinning, and wetland/riparian restoration are addressed in this report, but they are not thoroughly evaluated, nor are the results validated. With juniper clearing and forest thinning, hydrologic simulations estimated only slight increases in stream flow even though water available for surface runoff or deep percolation increased dramatically. Not having a calibrated ground water component in the MIKE SHE model probably skewed stream flow results. Research conducted on Sprague River riparian and wetland areas demonstrated the importance of understanding the timing and availability of soil moisture to support the establishment and survival of riparian and wetland vegetation.

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# 1. Introduction

The Sprague River CEAP study was initiated as a special emphasis watershed project in 2004 by the Natural Resources Conservation Service (NRCS) through a national program known as the Conservation Effects Assessment Project (CEAP). This national program began in 2003 as a multi-agency effort to quantify the environmental benefits of conservation practices used by private landowners participating in selected United States Department of Agriculture (USDA) conservation programs. Funding from CEAP has provided a unique opportunity to address current issues in the Sprague River Watershed while also providing insights into the methodologies that can be used to measure the effectiveness of conservation in similar watersheds throughout the western United States.

The Sprague River Watershed, part of the Klamath Basin in south-central Oregon, was selected because it has ranching, irrigation, and forestry uses common to much of the western United States. Much of the west, as in the Sprague River Watershed, has been confronted with resource issues surrounding water use, water quality, and endangered species.

## 1.1 Study Goals and Objectives

The Sprague River CEAP study was formulated to help solve water and endangered species issues affecting agriculture in the Klamath Basin. The goal of the study was to facilitate informed, adaptive management decisions contributing to agricultural sustainability, as well as the recovery and maintenance of threatened and endangered species.

NRCS's primary objective in the Sprague River CEAP study was to understand the effect land management activities (forest thinning, juniper control, irrigation water management, wetland/riparian restoration, etc.) have on the watershed's hydrologic budget. The Danish Hydraulic Institute's integrated hydrologic model, MIKE SHE<sup>1</sup>, was used to simulate the effects of these types of conservation practices. Extensive field monitoring provided the data that were used to calibrate and validate the hydrologic model.

## 1.2 Watershed Characterization

The Sprague River Watershed (see map on page 6) covers 1,021,300 acres in south-central Oregon. Approximately 44 percent of the land in the Sprague River Watershed is privately owned. Most of the remaining public lands are occupied by the Fremont-Winema National Forest.

Forested mountain ridges enclose the Sprague River Valley. Juniper and sagebrush steppe vegetation dominate range sites between the valley floor and the forested hills. The vast majority of private range and forest lands are used for livestock grazing.

The Sprague River Valley is used predominately for forage production on 48,500 acres of irrigated pasture. An estimated 125,000 acre-feet of water are diverted annually from the river or pumped from the regional aquifer for irrigation.

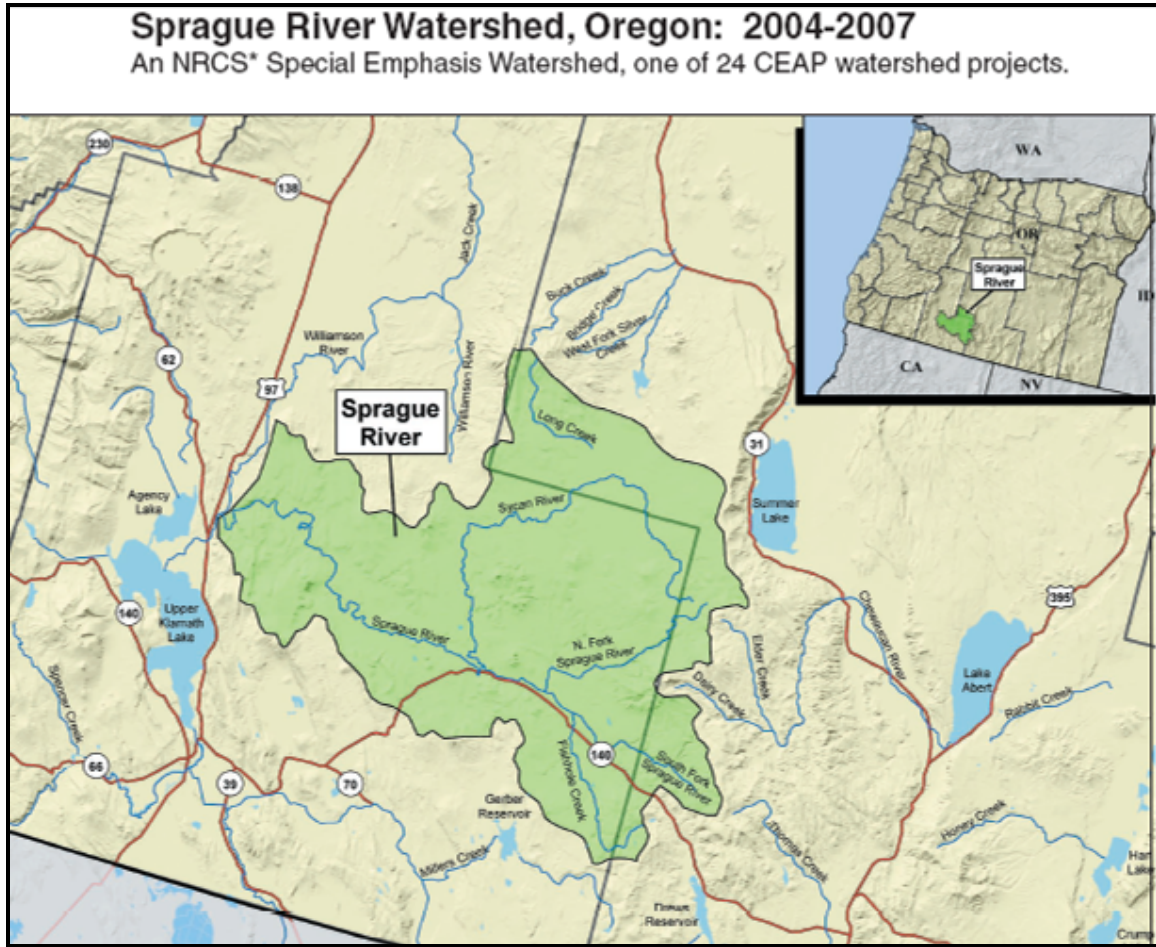


Figure 1. General Location Map of the Sprague River Watershed.

Annual precipitation in the watershed ranges from 47 inches along the eastern mountain ridges (8,200 feet elevation) to 15 inches along the valley floor (4,200 feet elevation). Most precipitation occurs from November to April, predominately as snow at higher elevations.

Soils in both the valley and the surrounding mountains are of volcanic origin. The valley soils are very deep, poorly drained silty clay and silty clay loams that formed in alluvium with varying amounts of ash. Excessively well-drained pumice soils dominate much of the watershed's uplands.

The Sprague River flows east to west for a total length of approximately 120 miles. Its headwaters include reaches draining from the Gearhart Mountains in the east and the 30,000-acre Sycan Marsh to the north. The lower river meanders considerably along the valley floor where anthropogenic changes to the channel have occurred over the last



century. The stream flow peaks with the spring snowmelt; however, the base flow is maintained by large artesian springs, as well as shallow seeps from riparian and wetland areas along the river.

The Sprague River yields an annual average of 418,000 acre-feet of water, representing 30 percent of the total annual inflow into the Upper Klamath and Agency Lakes.<sup>2</sup>

### 1.3 Resource Concerns

The Sprague River Watershed has been identified by the National Academy of Sciences, as well as individual scientists, as an area important for the overall resolution of water and endangered species issues in the Klamath Basin.<sup>3</sup>

The Sprague River Watershed contains significant habitat for endangered, river spawning Lost River and shortnose suckers. Water yield from the Sprague River is used downstream for fish and wildlife, as well as for irrigation on the United States Bureau of Reclamation Klamath Project.

Fish habitat in the Sprague River has been degraded by water withdrawals, channelization, increased stream temperatures, high nutrient concentrations, and the resulting growth of periphytic algae and aquatic macrophytes. In 2002 the Oregon State Department of Environmental Quality (ODEQ) completed a Total Maximum Daily Load (TMDL) for temperature, dissolved oxygen, and pH, confirming these observations<sup>4</sup>.

Recent decisions regarding the Federal Energy Regulatory Commission in the re-licensing process for Klamath River dams now require fish passage at hydropower

facilities to reintroduce salmon into the Upper Klamath Basin. With appropriate restoration and management, the Sprague River and its tributaries could provide essential spawning and rearing habitat for these salmon.



Figure 2. Photo of Sprague River Riparian Area.

## 1.4 Conservation Status

NRCS completed a rapid sub-basin assessment of the Sprague River in 2004.<sup>5</sup> This study recommended the implementation of 28,500 acres of irrigation water management, 6,000 acres of riparian/wetland restoration, 77,200 acres of improved range management, 6,700 acres of juniper control, and 61,000 acres of forest thinning. These practices were recommended to reduce water demand and increase water yield in order to augment summer base flows, restore riparian/wetland habitat, and improve water quality for endangered suckers and other fish.

Since 2002, landowners receiving technical and financial assistance through the Farm Bill have applied 2,200 acres of irrigation water management, 3,200 acres of riparian/wetland restoration, 5,400 acres of improved range management (prescribed grazing), 200 acres of juniper control (brush management), and 1,400 acres of forest thinning (forest stand improvement).<sup>6</sup> A total of 4,800 acres of wetlands and 1,200 acres of riparian areas have been enrolled in the Wetland Reserve and Conservation Reserve Enhancement Programs. Other federal, state, and local agencies have also targeted conservation efforts in this watershed, as evident on the following map.

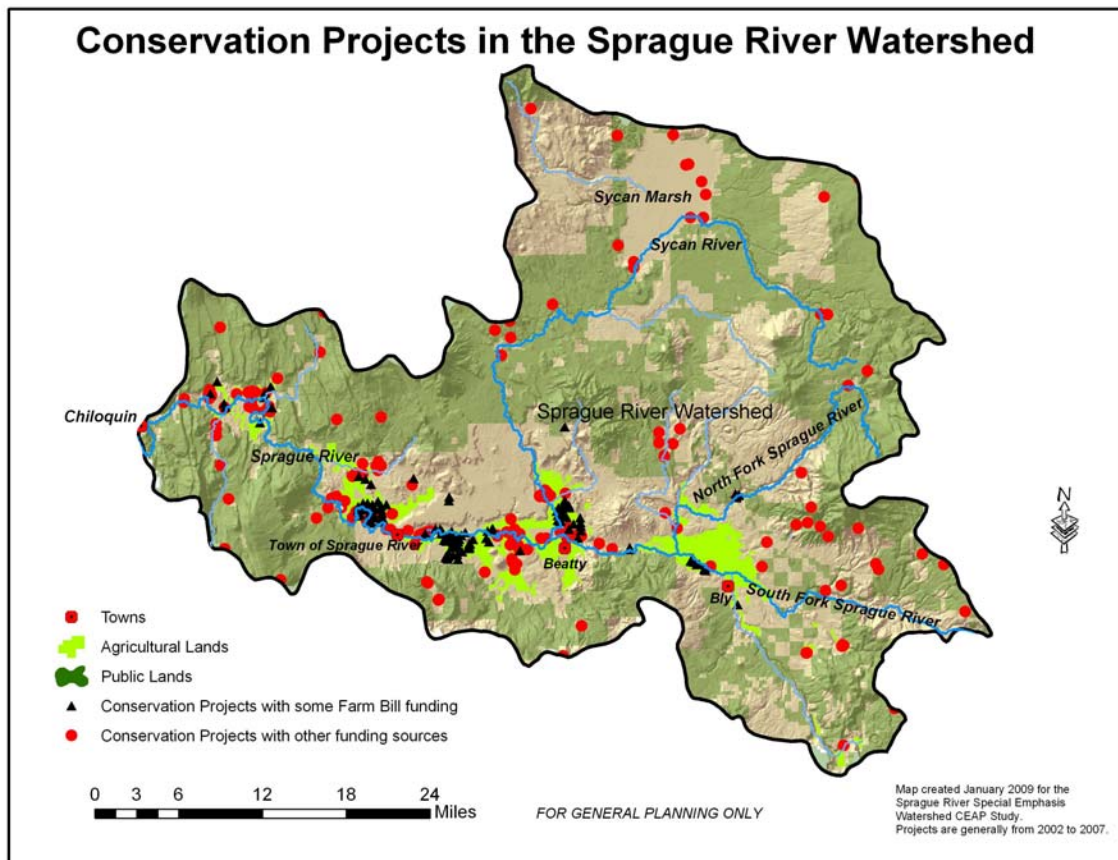


Figure 3. Map Showing Conservation Projects in the Sprague River Watershed.

## 1.5 Conservation Effects

Few attempts have been made to monitor and evaluate the effects of applied conservation practices in this area to determine their success. The data that were collected regarding these conservation efforts was neither thoroughly analyzed nor reliable because the timeframe was too short to be statistically significant. Observations by landowners and others suggest some positive effects from conservation efforts in the watershed but many have also raised important questions which are discussed below in terms of each land use.

### *1.5.1 Irrigated Grazing Lands*

Some believe livestock grazing and irrigation in the Sprague River Valley has negatively impacted stream flow, habitat, and water quality. Others say flood irrigation has had a positive impact because it mimics a river's overflow onto its natural floodplain. And a few ranchers have stated that their use of ground water for irrigation supplements summer base flow in the Sprague River.

Yearling livestock operations bring in 300-pound calves in the spring and export 800 to 1,000 pound animals in the fall. Forward looking infrared radar (FLIR) data collected by the Oregon Department of Environmental Quality (ODEQ) suggests subsurface return flow from flood irrigated fields may be cooler than the ambient stream temperatures. Water quality samples collected for this study reveal shallow ground water high in dissolved nutrients. This raises important questions about the effects of conservation practices used to improve grazing and irrigation management, such as: *(1) How do practices that improve irrigation efficiency affect the timing, amount, and quality of surface and subsurface return flows? (2) What effect do practices that enhance irrigation efficiency have on stream flows? (3) Does ground water pumping for irrigation impact stream flows and ground water availability? (4) How does improved irrigation efficiency affect the application uniformity and the total evapotranspiration of water by plants? (5) How might different irrigation practices affect water quality?*



Figure 4. Photo of Good Forage Management.



Figure 5. Photo of a Gated Pipe Irrigation System.

### 1.5.2 Forest and Range Lands

Conservationists hypothesize that thinning overstocked western ponderosa and lodgepole pine forests could increase annual runoff by reducing moisture losses from canopy interception and evapotranspiration.

Foresters often cite anecdotal evidence of increased spring and stream flows after natural thinning occurs through events such as forest fires. Furthermore, ranchers frequently claim that new springs often appear below areas cleared of encroaching juniper. This CEAP study attempts to answer questions such as: (1) *Does forest thinning or juniper removal significantly increase stream flow?* (2) *How do these practices impact soil moisture levels and surface runoff?* (3) *Does increased runoff occur at times when it is needed downstream for fish, wildlife, or irrigation?*



**Figure 6. Photo of a Juniper Clearing Project.**

### 1.5.3 Wetland and Riparian Areas

In general, wetland and riparian area restoration is thought to improve the water holding capability (sponge effect) of lands surrounding the stream. This would allow these lands to store clean, cool water for a later release that will maintain the stream's base flow. Landowners at restoration sites often report greater forage production in their meadows following stream and riparian area restoration projects. Important questions on the effects of wetland and riparian area restoration that this study addresses include:



(1) *How much water can be stored in the soils and for how long?* (2) *Is the water returned to the stream from restored wetland/riparian areas cooler and cleaner compared to the water returned under previous management strategies?* (3) *Does riparian/wetland restoration increase sub-irrigation and forage production in adjacent meadow pastures?*

**Figure 7. Photo of Good Riparian Management.**

#### *1.5.4 Overview*

This study attempts to provide decision-makers with relevant information regarding conservation practices that will address their questions and concerns. The study focused on conservation practices related to the irrigation of grazing lands in the Sprague River Valley, and it included a preliminary simulation of the effects of conservation practices, such as juniper removal and forest thinning. While the study indicates the need to understand the hydrologic budget in order to effectively restore and manage wetland/riparian areas, time and funding constraints limited the researchers' ability to conduct a complete assessment following the selected methodology.

## 2. Study Methodology

Most questions concerning the effects of conservation applied to or recommended for the Sprague River Watershed relate to the hydrologic budget. Once the hydrology is fully understood, it will be easier to determine specific conservation effects on other resource concerns, such as water quality and fish and wildlife habitat.

This CEAP project used three linked strategies to study conservation effects:

1. *Collection and analysis of existing data* (stream flow, water quality, etc.) in order to establish benchmark conditions and evidence of cause and effect relationships.
2. *Monitoring and evaluation of new data* that are on-site and field specific in order to better quantify changes in the water budget stemming from conservation activities like irrigation water management, riparian/wetland restoration, and upland management on forest and range lands.
3. *Modeling the watershed* with hydrologic and water quality models to estimate the cumulative effects of conservation practices.

To fully understand the hydrology of the Sprague River Watershed and the effects of conservation efforts, the NRCS hydraulic engineers suggested using a calibrated and validated hydrologic model. To encompass the range of resource issues and conservation alternatives being considered, they concluded the model should:

- Be fully dynamic, distributed spatially and temporally, and physically based;
- Incorporate all parts of the hydrologic cycle – saturated and unsaturated zones, surface runoff, channel hydraulics, evapotranspiration, snow melt, and canopy interception losses;
- Simulate the effects of management scenarios such as wetland restoration, irrigation practices, forage management, forest thinning, brush control, and stream channel restoration;
- Be sensitive to geographical location and unique slopes, aspect, soils, vegetation, and meteorology; and
- Estimate sediment and solute (pollutant) transport.

After carefully reviewing the literature and considering outside advice from other agency experts, consultants, and academia, the Danish Hydraulic Institute's MIKE SHE software<sup>1</sup> was selected as the model most appropriate for accurately answering questions regarding the effectiveness of conservation in the Sprague River Watershed. The Danish Hydraulic Institute (DHI) has developed a suite of hydrologic software programs covering river and channel hydraulics, surface and groundwater hydrology, flood forecasting as well as marine and urban hydrology. Most DHI software programs are referred to as "MIKE" models, such as MIKE SHE, MIKE 11, etc.

## 2.1 MIKE SHE Hydrologic Model<sup>1</sup>

The MIKE SHE is an integrated hydrological modeling system which covers the entire land phase of the hydrological cycle (see the diagram on the following page). The model is coupled with MIKE 11, which is a one-dimensional channel hydraulics program. MIKE SHE also includes a ground water hydrology routine (saturated zone) similar to MODFLOW ground water model used by the U.S.G.S. and others.

Flexibility is built into MIKE SHE by the use of several alternative algorithms to describe the hydrologic processes as shown in the table below. These alternative descriptions allow the user to choose the most appropriate algorithm based on the importance of each hydrologic process for the situation being simulated. For less critical processes in a given situation, less complex algorithms can be used to save computational time and memory.

<b>Hydrologic Process</b>	<b>Alternative Algorithms</b>
Channel Flow (MIKE 11)	<ul style="list-style-type: none"> <li>• Kinematic wave approximation</li> <li>• Diffusive wave approximation</li> <li>• Fully dynamic solution (St. Venant equations)</li> <li>• Muskingum routing</li> <li>• Muskingum-Cunge</li> </ul>
Overland Flow	<ul style="list-style-type: none"> <li>• 2D diffusive wave</li> <li>• Conceptual reservoir routing</li> </ul>
Evapotranspiration	<ul style="list-style-type: none"> <li>• Shuttle-Worth Wallace (2-layer)</li> <li>• Kristensen &amp; Jensen (Danish Model)</li> <li>• Net Precipitation</li> </ul>
Unsaturated Flow	<ul style="list-style-type: none"> <li>• 1D Gravity drainage</li> <li>• 1D Richards equation</li> <li>• Two layer approximation</li> </ul>
Saturated Flow	<ul style="list-style-type: none"> <li>• 2D Boussine wq approximation</li> <li>• 3D Darcy flow</li> <li>• Linear reservoirs</li> </ul>

All the hydrologic processes in the MIKE SHE/MIKE 11 model are dynamically linked so that changes to one process can affect all other processes in the model. The effect of changing one parameter (e.g. in the unsaturated zone) may affect multiple parameters such as overland irrigation return flows, evapotranspiration, river stage, etc.

There is a strong relationship between the surface water and ground water processes in the Sprague River Watershed. For irrigation simulations at the ranch scale (Section 3.1) and reach scale (Section 3.2), the saturate zone (SZ) component of the model only simulated the upper shallow, perched aquifer. At these localized scales the inclusion of only the shallow aquifer in the SZ model is sufficient to simulate the ground water

drainage to the river and its effects on river stage and ponded water on the floodplain. In contrast, these same parameters at the sub-watershed level (Section 3.5), where a regional deeper aquifer was simulated, would affect the potential head and dynamics of the water levels.

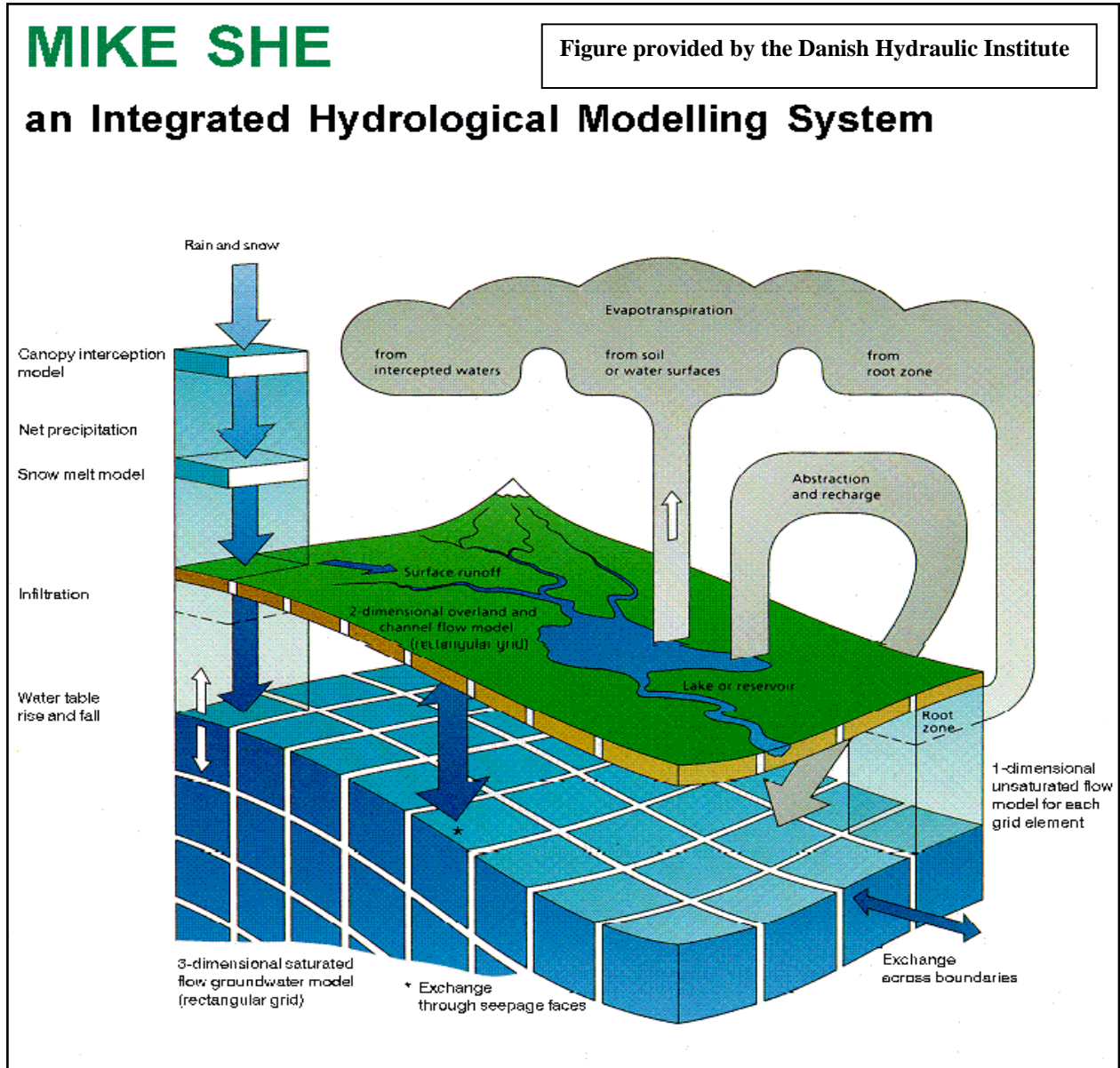


Figure 8. Diagram Depicting the MIKE SHE Integrated Hydrologic Modeling System.

The main parameters used in the Sprague River MIKE SHE model are listed in the following table. Soil properties in the unsaturated zone affected the retention curve and unsaturated hydraulic conductivity, which influenced shallow ground water levels, evapotranspiration rates, and ground water recharge. This was of particular interest in the irrigated areas as the evapotranspiration rates are directly related to the consumption of water by the pasture grasses and are thus representative of production.



The evapotranspiration parameters for the Kristensen and Jensen algorithm in MIKE SHE were empirical and generally set at the default values. The main calibration inputs were the leaf area index (LAI) and crop coefficient (Kc), which may have changed the total evapotranspiration and distribution over the year as it is represented in the model. In an independent test of the Kristensen and Jensen ET algorithm, Oregon State University (OSU) found that the algorithm produced reasonable results compared to their measured data<sup>7</sup>. OSU tested the model at the Reynolds’s Creek watershed in Idaho at three different elevation zones. Reynolds’s Creek is similar in soils, geology, and climate to the Sprague River Watershed. OSU found that the MIKE SHE ET algorithm produced excellent results in the mid-elevation zone (3,900 to 5,500 feet). Most of the Sprague River Watershed lies within these elevations.

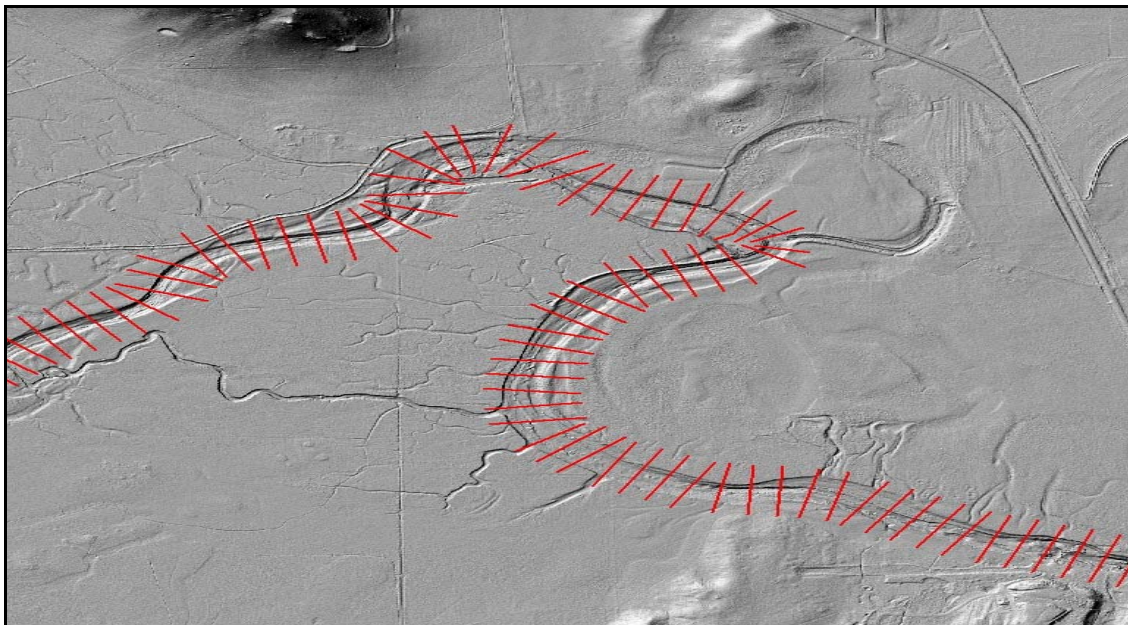
<b>Table 2: MIKE SHE Model Components.</b>		
<b>Model Component<sup>1</sup></b>	<b>Model Input</b>	<b>Model Parameters</b>
MIKE SHE SZ Saturated zone flow	Hydro geologic layers, Boundary conditions, Initial potential heads.	K <sub>h</sub> , Horizontal hydraulic conductivity K <sub>v</sub> , Vertical hydraulic conductivity S, Specific Yield S, Storage coefficient
MIKE SHE UZ Unsaturated zone flow	Map of characteristic soil types, Hydraulic Conductivity Curves, Soil-Water Retention curves.	Ks, saturated hydraulic conductivity Θ <sub>s</sub> Saturated water content Θ <sub>res</sub> Residual water content pF <sub>c</sub> , Capillary pressure at field capacity pF <sub>w</sub> , Capillary pressure at wilting point n, Exponent of hydraulic conductivity curve
MIKE SHE ET Evapotranspiration	Time series of vegetation Leaf Area Index, Time series of vegetation Root depth.	C <sub>1</sub> , C <sub>2</sub> , C <sub>3</sub> : Empirical parameters C <sub>int</sub> : Interception parameter A <sub>root</sub> : Root mass parameter Kc : Crop coefficient
MIKE SHE OL Overland and river/canal flow (MIKE11)	Topographical map, Boundary conditions, Digitized river/canal network, River/canal cross sections.	n, Overland Manning no. D, Detention storage L, leakage coefficient n, River Manning no.
MIKE SHE IRR Irrigation module	Irrigated area Water source (surface, well, or external) Application method (sheet, sprinkler, or drip) Source capacity	Temporal distribution Demand rate of application

Overland flows and river flows are directly affected by surface and channel roughness, described by Mannings “n” coefficient. This can change the downstream stage elevations and runoff into rivers from precipitation and irrigation. A detention coefficient is a

threshold value where runoff is assumed to occur after reaching this threshold. This may affect the contribution of surface water to the river and unsaturated zone, in turn affecting ground water levels. The leakage coefficient of the surface and river lining controls the exchange of surface water and ground water.

A temporal and spatial distribution and rate of application for applied irrigation water can have a significant impact on ground water levels, evapotranspiration rates, surface flows, and river levels. The MIKE SHE Irrigation module can be set to irrigate automatically based on the crop water demand or be based on an inputted irrigation schedule. The latter method was used in this study to more accurately portray typical landowner irrigation management (timing and rates of application) and water rights.

Floodplains are often characterized by two-dimensional flow, and this was accomplished by linking the 1-dimension MIKE 11 channel hydraulic model to the 2-dimension overland flow component within MIKE SHE. River flows in the watershed are described by the 1-dimension fully dynamic river model MIKE 11, which couples dynamically to the integrated hydrologic MIKE SHE model. All surface flowways or channels can be accounted for in the model, including main rivers, tributaries, and irrigation canals. Surface runoff is calculated by the MIKE SHE overland flow component, which is dependent on the topographic gradients and the overland Manning's roughness coefficients. MIKE SHE runoff flows into the rivers/canals in MIKE 11 that are coupled to MIKE SHE model and where the water levels and bank elevations are lower than the water levels in the adjacent MIKE SHE cells. For this study, only the main rivers were simulated in MIKE 11 and coupled to MIKE SHE. The 2-dimension flow associated with irrigation return flows across the agricultural fields was also simulated within the overland flow component and allowed to transfer between the floodplain and the river. Cross sections for the MIKE 11 model were generated from merged LiDAR and bathymetry data for the ranch and reach scale models.



**Figure 9. Representation of MIKE 11 Cross Section Spacing and Widths.**

MIKE SHE model, like all models, must be calibrated and validated in order to increase confidence in the results. To confirm its accuracy, the Sprague River CEAP study incorporated extensive ground-truthing and field monitoring to document stream flows, water table levels, soil moisture content, water quality sampling, vegetation, leaf area index, and other parameters. The chosen parameters were identified as those most likely to be sensitive to changes in inputs or outputs to the model and those most relevant to conservation management actions.

The Oregon NRCS Water Resources staff worked closely with other scientists and local stakeholders to collaborate on the data, science, and methodologies to ensure that this study would provide the most relevant and accurate information possible.

The NRCS staff in Oregon took the lead on coordinating the study, conducting field monitoring, and modeling the watershed. NRCS contracted the University of



Washington and Oregon State University for assistance with model parameterization and evaluation. NRCS also worked closely with the United States Geological Survey (USGS) and the Oregon State Department of Water Resources (OWRD), who were conducting a regional ground water study, including the simulation of ground water hydrology for the Upper Klamath Basin.

**Figure 10. Photo of the Installation of a Piezometer to Measure Water Table Levels.**

## **2.2 Other Hydrologic Models**

In the original 2004 Sprague River CEAP proposal, it was stated that the performance of two public domain hydrologic models (AnnAGNPS and DHSVM) would be compared to the proprietary MIKE SHE model.

The Agricultural Non-Point Source Pollution Model (AnnAGNPS)<sup>8</sup> is a system of computer models developed by the USDA to predict agricultural pollutant loadings within watersheds. After reviewing the AnnAGNPS, Oregon NRCS and the NRCS National Water Management Center agreed that it was not an appropriate model to use on the Sprague River Watershed. Limitations of the AnnAGNPS included:

- No saturated zone component to simulate ground water hydrology and its interaction with surface hydrology,

- Routines to handle snow melt and frozen soils were still under development,
- A lumped parameter model based on curve numbers rather than physical processes, and
- AnnAGNPS focuses on simulating hydrology for cultivated agricultural areas, whereas the dominate land uses in the Sprague River Watershed consists of forest, range, and non-cultivated agriculture (pasture).

The Distributed Hydrology Soils Vegetation Model (DHSVM) is a research model developed by the University of Washington.<sup>9</sup> This model is physical process based, similar to MIKE SHE. The DHSVM has been used by the Land Surface Hydrology Research Group at the University of Washington, as well as by others, to study hydrologic effects associated with forest management activities. The DHSVM was not used for this study because of two limiting factors:

- It has no routines to simulate irrigated agriculture, and
- The model is not dynamically linked to ground water hydrology, which is believed to be an important part of the hydrologic cycle in this watershed.

### **2.3 On-going, Related Conservation Studies in the Sprague River Watershed**

NRCS also collaborated on two specific studies (described below) to complement the Sprague River CEAP study:

1. The USGS and the Klamath Tribes conducted an evaluation of existing water quality data. (See Section 2.16 for a summary of the results).
2. The University of Oregon has completed a survey and preliminary evaluation of the vegetative responses to riparian/wetland restoration projects along the Sprague River. A final report is expected soon. Preliminary results from this study are discussed in Section 3.6.

In addition to these two studies, an informal science team comprised of other agencies and organizations involved in related studies in the Upper Klamath Basin met regularly to help guide data collection and analysis, field monitoring and evaluation, and modeling efforts. Additionally, several other NRCS conservation partners are engaged in other on-going studies and data collection efforts akin to the Sprague River CEAP study. The following table briefly describes these studies and explains how they complement NRCS's CEAP efforts.

**Table 3: On-Going Studies and Data Collection Efforts.**

<b>Study Title (Entity Created By)</b>	<b>Description</b>	<b>NRCS Funded</b>	<b>Information Related to or Used in the NRCS CEAP</b>
Water Quality Assessment of Nutrient Dynamics (USGS/Klamath Tribes)	Water quality monitoring has been conducted by the Klamath Tribes, Oregon State Department of Environmental Quality, USGS, and others for several years. This assessment by USGS evaluates this data to explain nutrient dynamics in the Sprague River Watershed.	Yes	NRCS, with the Klamath Tribes, funded the USGS to conduct this study to provide more insights into nutrient dynamics related to land management activities.
Riparian Vegetation Survey/Evaluation (U of O)	This study will characterize riparian vegetation and channel responses to restoration efforts and land management activities.	Partial	It will provide estimates of riparian vegetation responses to restoration efforts and adjacent land management activities along with its correlation to hydrologic conditions.
Regional Ground water Study (USGS/OWRD)	This regional ground water study was conducted by the USGS with OWRD assistance. The study will characterize and quantify the ground water flow system and simulate the effects of land use/land management activities.	No	The USGS expertise and data from this study helped set up the ground water module of the MIKE SHE model.
Evapotranspiration (OSU)	ET is an important driver of the hydrologic budget. OSU has tested the ET component of MIKE SHE and has found its ET algorithms to be accurate for the vegetation and climate found in the Sprague River Watershed.	Yes	It validated the Jensen-Kristensen ET algorithm used in MIKE SHE, and created recommendations on crop parameters.
LiDAR/ Bathymetry (Klamath Tribes/ NRCS)	Through a collaborative effort between the Klamath Tribes and NRCS, detailed elevation data (LiDAR) and channel bathymetry (hydro-acoustics) were acquired for most of the Sprague River Valley.	Partial	It detailed valley and channel cross sections to use in MIKE SHE, as well as a topographic map for use in monitoring and planning.
Channel Geomorphology Study (USGS/U of O)	This study will provide a description of geomorphologic and hydrological processes in the Sprague River, which will aide future restoration efforts.	No	It will provide information on expected channel responses to different stream/riparian area restoration alternatives.
Geomorphology/ Sedimentation (Klamath Tribes/ Graham Matthews)	This study has similar objectives as the USGS/U of O study with some differences in methodology and with additional information on the detachment, deposit, and transport of sediments.	No	It provides data on channel and riparian area restoration effects on sediment and water quality.
Fish Surveys and Evaluations (USGS/FWS)	Studies are underway to monitor fish (ESA endangered suckers) movement, life cycle, and habitat requirements in the Sprague River.	No	It will improve our understanding of critical water quality and the aquatic and riparian habitat needs of suckers and other fish species.
Soil Survey (NRCS/USFS)	Second order soil survey for Klamath County is currently being re-mapped and updated.	Partial	Improvement in understanding of soils and their characteristics that influence hydrology.

The Sprague River CEAP study, through collaborative efforts with others, created the best scientific estimate of conservation effects within the limits of available resources and time. These results helped us to understand problems and issues surrounding the Sprague

River Watershed and also provided the opportunity to test the functionality and accuracy of the technologies used in the CEAP study and the other studies listed above.

## 2.4 Data Collection, Field Monitoring, and Analysis

Data on ground water levels, river levels, soil moisture, precipitation, irrigation records, and water quality were collected where applicable on six properties in the Sprague River Watershed. (See the table and map on next page).

The data collected were used to calibrate and validate the MIKE SHE hydrologic model. The data also revealed relationships between the movement of water across the land surface and through the soils compared to the expected effects of practices such as irrigation water management, wetland restoration, and river management.

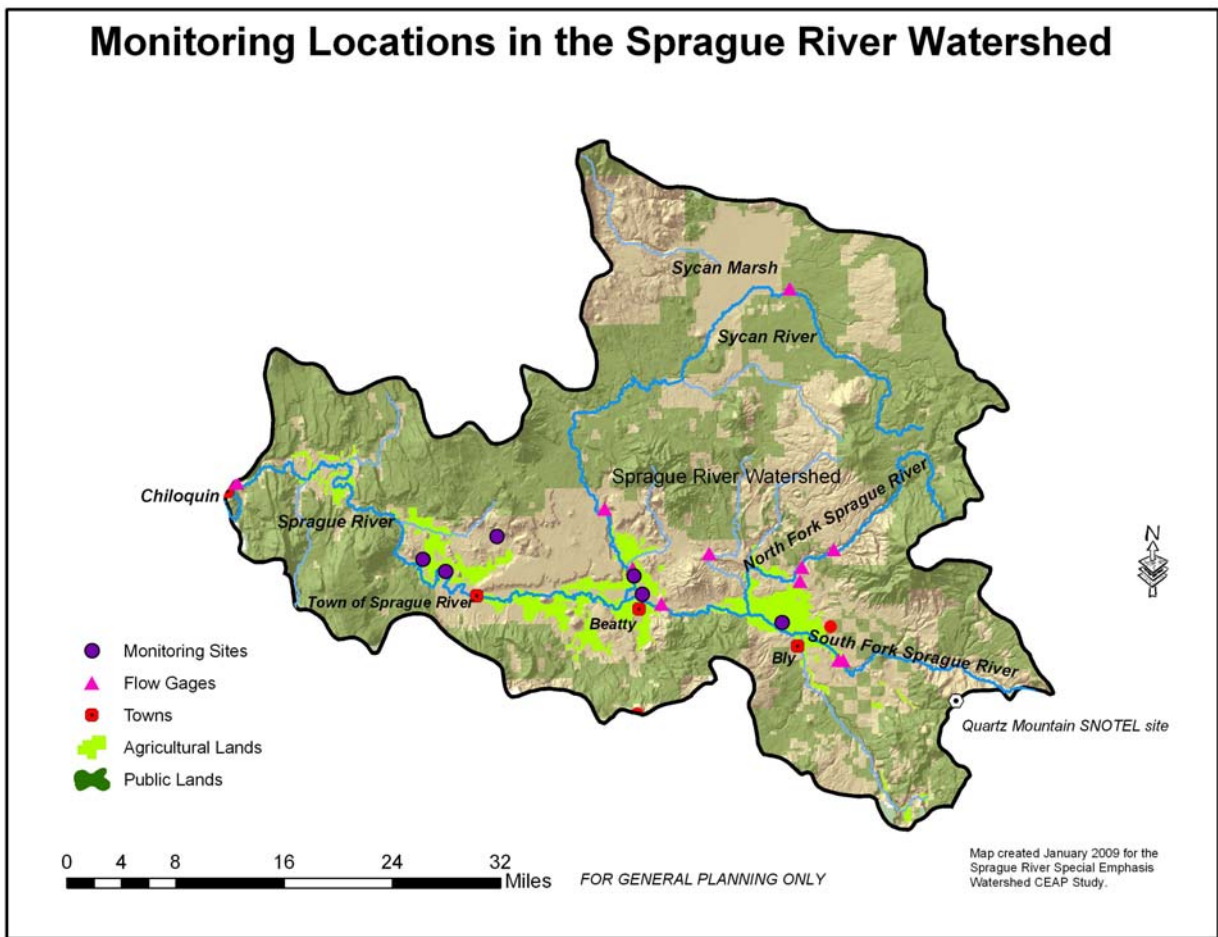


Figure 11. Map of Monitoring Locations in Sprague River Watershed.

**Table 4: NRCS Sprague River CEAP – Field Monitoring Site Locations.**

Properties	Description	Stream Level	Ground Water Level	Soil Moisture	Precipitation	Irrigation Records	Water Quality
1	Irrigated Pasture-Wild Flood Irrigation (2005) converted to Gated Pipe (2006)	✓	✓	✓	✓	✓	✓
2	Irrigated Pasture-Wild Flood, Center Pivot, Wheeline Sprinklers	✓	✓	✓	✓	✓	
3	Irrigated Pasture/Hay-Wild Flood, Center Pivot Sprinklers	✓	✓	✓	✓	✓	
4	Non-Irrigated Pasture Limited Grazing-Scheduled to be converted to wetland (WRP)	✓	✓	✓	✓		✓
5	Non Irrigated/Wetland (WRP)-Stream restoration project (2006)	✓	✓				
6	Upland Range/Juniper Site		✓				

## 2.5 Meteorology

Weather drives the hydrologic cycle. Inputs to the MIKE SHE model include meteorological data such as precipitation, air temperature, wind speed, and solar radiation. At a watershed scale, climatic data must also be distributed across the simulated landscape. Precipitation ranges from 15 inches annually in the Sprague River Valley to about 47 inches in the surrounding mountains. More precipitation accumulates in the winter than the summer months as snow at higher elevations. Temperature, wind speed, and solar radiation, which affect evaporation and transpiration, also can vary across the landscape. Timing also impacts the water budget. Intense rainfall over a short time (a few hours) generates more runoff versus the same amount of rainfall over many days. To simulate the hydrologic budget accurately for a watershed therefore requires a temporal, spatially distributed dataset.

From prior implementations of the Distributed Hydrology Soils Vegetation Model (DSHVM) at the University of Washington,<sup>10</sup> an approach for preparing weather station data for input into the DHSVM model was written in part by Dr. Andrew Wood. The NRCS National Water and Climate Center (NWCC) recommended the University of Washington's approach to generate the required meteorological inputs for the MIKE SHE model.

The primary meteorological data used in this approach included daily precipitation, temperature minima and maxima, and wind speed taken from stations both in and around the basin. The station data were screened for unrealistic values, and missing values from the daily station dataset were estimated to form a continuous set of inputs. This was accomplished by cross correlations between all stations listed in the dataset. These in turn were used to disaggregate the daily data to a three-hour time step and to estimate

additional forcing variables (relative humidity as well as solar and long wave radiation). Twenty-seven stations from the National Climatic Data Center (NCDC) Cooperative Observer network and the NRCS SNOTEL (snowpack telemetry) network were used in estimating missing forcing variables from October 1, 1978, to September 20, 2007. Of these, the 11 stations nearest the basin were ultimately used in generating meteorological data sets (see map below).

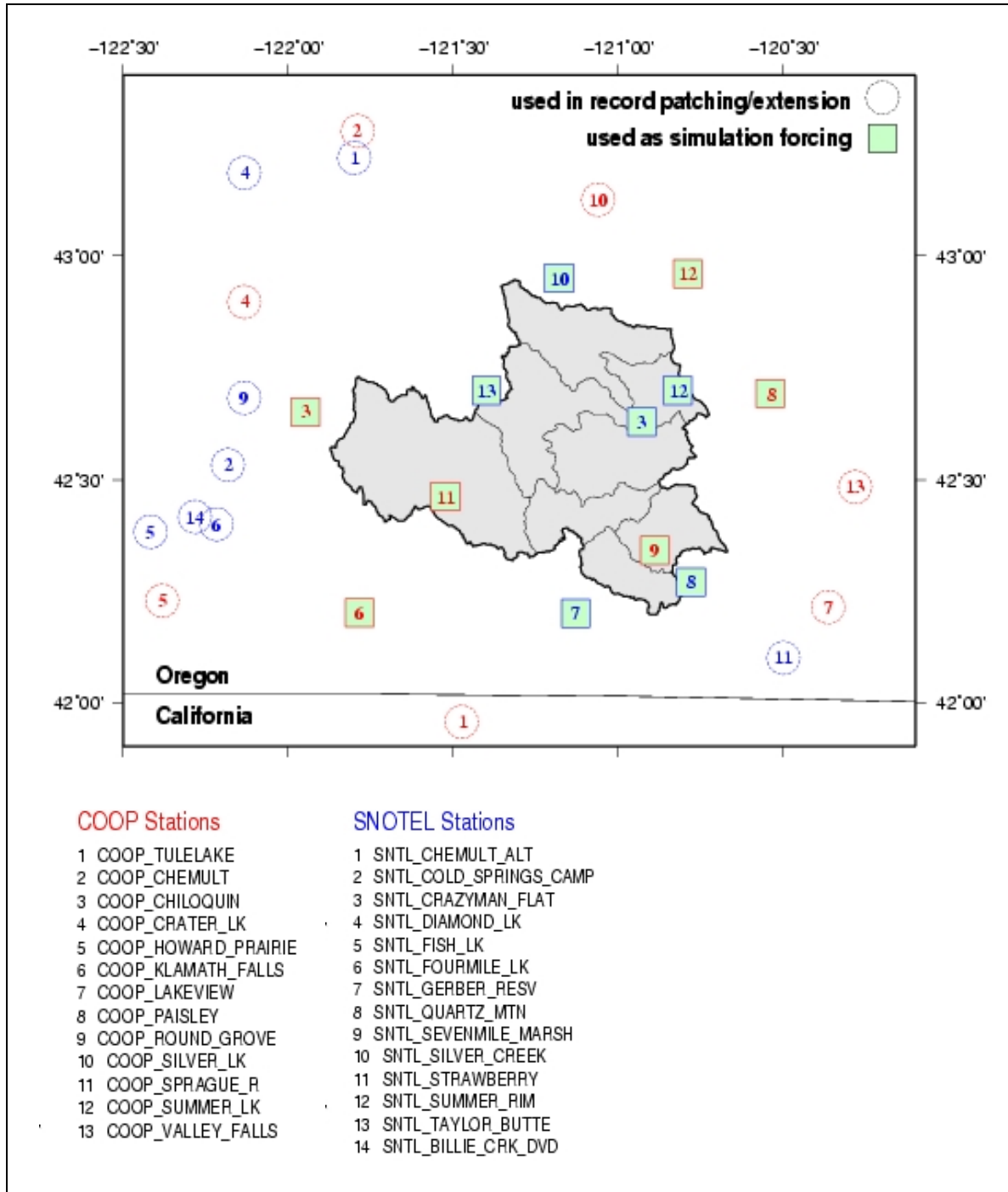


Figure 12. Map of Weather Stations Used to Generate Meteorological Data.



PRISM maps<sup>11</sup> of monthly, long-term precipitation averages (at 2.5 kilometer spatial resolution) were used to distribute the station precipitation to each grid cell in the basin simulation. These PRISM maps (one for each calendar month) formed one set of parameter inputs for the model. Temperature data, on the other hand, were interpolated and lapsed to each grid cell elevation according to user-specified lapse rates. The pseudo-adiabatic lapse rate of 6.5 degrees Celsius per kilometer was adopted in the Sprague River Watershed model.

The map above shows the meteorological stations used to create the daily, three-hour climate data. Those sites plotted as squares were used as forcings for the simulation, whereas those plotted as circles were used for patching missing data points. Blue symbols represent SNOTEL stations and red represent Co-op stations.

## **2.6 Reference Crop Evapotranspiration**

The MIKE SHE model calculates actual evapotranspiration (ET) based on the potential ET of a reference crop. Potential ET assumes a free water surface (water not limiting) with no vegetative cover, but varies with actual temperature, wind, and solar radiation. Reference ET converts potential ET to a reference crop such as alfalfa or grass.

As part of the process of generating the meteorological dataset, the University of Washington also generated a spatial time series dataset of reference ET for the Sprague River CEAP study. An implementation of the Penman-Montheith equation was used to estimate potential evaporation. Reference crop evaporation calculations assume an idealized reference crop of 0.12 meters and an albedo of 0.23 to approximate a short grass reference. A spatially distributed, three hour daily reference ET dataset was generated for the period from October 1, 1978, to September 20, 2007.

## **2.7 Vegetation Considerations**

Distributive hydrologic models respond to differences in vegetation type and management. Therefore it is important to correctly identify vegetation types, distribution, and characteristics unique to conservation management alternatives proposed. In the Sprague River Watershed, most pasture is located along the river's floodplain. It is sprinkler or surface irrigated and grazed at different intensities. Pasture is frequently flooded in the spring, sub-irrigated by high water tables, irrigated during dry summer months, and grazed intensely. The hydrologic budget affects the pasture's response to these activities and, conversely, the pasture impacts various components of the hydrologic budget (runoff, transpiration, evapotranspiration, deep percolation, etc.) and its timing. Often, grazing will impact wetlands and riparian areas by changing the composition and characteristics of the vegetation.

The properties and management of upland vegetation also can impact the quantity and timing of stream flows and ground water recharge. Rain and snow falling on dense, overstocked forest can be lost to evaporation and sublimation, leaving less soil moisture for the growth of trees and understory vegetation, and, at the same time, reducing surface

runoff. Western juniper have encroached upon native steppe sage habitats throughout its range in western states, including in the Sprague River Watershed, out-competing bunchgrasses, forbs, and sagebrush for water, thereby leaving less forage and browse for wildlife and cattle.

### 2.7.1 Vegetation Mapping

A detailed, gridded (three meter) GIS layer was created using several secondary sources, remote sensing, and ground-truthing. Secondary sources of information included:

- Oregon GAP Vegetation<sup>12</sup>,
- National Wetland Inventory (NWI),
- The Klamath Tribes Forest Management Plan<sup>13</sup>,
- Winema National Forest Ecological Unit Inventory<sup>14</sup>, and
- Oregon Department of Water Resources (OWRD) water rights database<sup>15</sup>.

Remote sensing was used to identify juniper, pine, and fir in canopy density classifications. This was accomplished using a program (WINCOV) written by retired forest ecologist Robert J. Lackey. The program uses digital ortho-photo quads to identify trees and cover percentage based on brightness and texture. This information was used to detail GAP forest vegetation into four canopy classes: 10-25 percent, 26-50 percent, 51-75 percent, and 76+ percent. The NWI was overlaid to identify wetland vegetation, including hundreds of small, wet meadows located in the forested uplands. The Klamath Tribes Forest Management Plan and the Fremont-Winema National Forest Plan were used to describe typical forest understory species and abundance.

Minor adjustments were made to forest vegetation data after extensive windshield surveys and the establishment of 36 forest vegetation transects to determine species, canopy density, understory vegetation, and leaf area index.

Irrigated pastures were first delineated based on the OWRD spatial point of use database for irrigated water rights. This layer was then further refined by NRCS through interpretation of digital orthophotography and extensive ground-truthing. Attributes were added to denote the irrigation type (wild flood, controlled flood, gated pipe, or sprinkler) and the irrigation source (stream or well).

### 2.7.2 Vegetation Characteristics (Parameters)

Besides the spatial distribution of vegetation types, the hydrologic model requires the user to describe several vegetative characteristics or parameters. These parameters include potential evapotranspiration rates, leaf area index, rooting depth and density, canopy interception, and crop coefficients.

Representative values for each vegetation type and the canopy densities were established through an extensive literature search, consultation with experts, and remote sensing and field measurements. For the pasture areas in the model different levels of irrigation and grazing management were specified. Again, the differences in these variables account for

many of the anticipated changes in the hydrologic budget expected from conservation management activities.

The leaf area index (LAI) for forest vegetation was obtained from a Landsat satellite interpretation made by Oregon State University<sup>16</sup> to determine the carbon budget of Oregon forests. Their interpreted values were compared to optical measurements made by NRCS with a LAI-2000 plant canopy analyzer at 36 transects, stratified for forest type and density within the Sprague River Watershed. Field measurements generally supported remotely sensed values. However, resolution errors using the 25 meter Landsat imagery with 300 foot linear transects made one-to-one comparisons difficult.

The crop parameters used in this study are summarized in the tables below.

**Table 5: Crop Parameters for Forest, Juniper, and Sage Steppe Vegetation.**

Veg Code	Veg Name	Canopy (percent)	LAI	Canopy Interception (percent)	Root Depth (cm)
38001	Western Juniper	10-25%	0.562	17.25	120
38002	Western Juniper	26-50%	0.715	24.75	120
38003	Western Juniper	51-75%	1.072	37.75	120
38004	Western Juniper	76+%	1.820	42.00	120
58001	Ponderosa-Juniper	10-25%	0.562	17.25	120
58002	Ponderosa-Juniper	26-50%	0.715	24.75	120
58003	Ponderosa-Juniper	51-75%	1.072	37.75	120
58004	Ponderosa-Juniper	76+%	1.820	42.00	120
39001	Whitebark-Pine Montane	10-25%	0.905	11.25	90
39002	Whitebark-Pine Montane	26-50%	1.389	16.25	90
39003	Whitebark-Pine Montane	51-75%	2.950	22.00	90
39004	Whitebark-Pine Montane	76+%	3.248	24.00	90
40001	Ponderosa, Mixed	10-25%	1.440	24.10	120
40002	Ponderosa, Mixed	26-50%	1.901	26.40	120
40003	Ponderosa, Mixed	51-75%	2.829	29.50	120
40004	Ponderosa, Mixed	76+%	4.207	28.60	120
44001	Lodgepole Pine	10-25%	0.405	18.43	60
44002	Lodgepole Pine	26-50%	0.665	18.93	60
44003	Lodgepole Pine	51-75%	1.056	20.50	60
44004	Lodgepole Pine	75+%	1.767	19.20	60
54001	Ponderosa Pine	10-25%	0.849	25.33	180
54002	Ponderosa Pine	26-50%	1.193	29.03	180
54003	Ponderosa Pine	51-75%	1.740	33.70	180
54004	Ponderosa Pine	76+%	2.605	31.95	180
59001	Ponderosa-Lodgepole	10-25%	0.849	16.05	75
59002	Ponderosa-Lodgepole	26-50%	1.193	18.45	75
59003	Ponderosa-Lodgepole	51-75%	1.740	23.15	75
59004	Ponderosa-Lodgepole	76+%	2.605	24.10	75
92000	Sagebrush Steppe, current	60%	0.555	26.00	165
92000	Sagebrush Steppe, treated	80%	0.200	13.00	80

**Table 6: Crop Parameters & Coefficients for Pasture & Wetland/Riparian Vegetation.**

<b>Veg Codes</b>	<b>Description</b>	<b>Julian Period</b>	<b>Stage</b>	<b>LAI</b>	<b>Root Depth (cm)</b>	<b>Kc</b>
21000	Pasture, Heavy grazing	0-79	Dormant	0.300	45	0.010
		79-105	Early Spring	0.350	45	0.455
		106-135	Spring	0.750	45	0.712
		136-232	Summer	1.000	45	0.826
		233-260	Early Fall	0.750	45	0.776
		261-290	Late Fall	0.450	45	0.472
		291-366	Winter	0.300	45	0.010
21000	Pasture, Light grazing	0-79	Dormant	0.500	45	0.010
		79-105	Early Spring	0.600	60	0.501
		106-135	Spring	0.850	60	0.864
		136-232	Summer	1.800	60	1.013
		233-260	Early Fall	1.300	60	0.926
		261-290	Late Fall	1.100	60	0.538
		291-366	Winter	0.500	60	0.010
25000, 26000, 27000, 29000, 32000	Wet Meadow, WRP, Wetland Emergent, Palustrine, & Lacustrine	0-79	Early	0.350	60	0.400
		80-110	Spring	2.000	60	0.275
		111-135	Summer	3.300	60	0.260
		136-213	Late Summer	2.000	60	0.891
		214-258	Fall	1.300	60	1.100
		305-366	Winter	0.350	60	0.317
30000, 31000, 121000	Wetland Forest, Scrub Shrub, Grass Shrub	0-79	Early	0.500	120	0.43
		80-110	Spring	1.500	120	0.47
		111-135	Summer	3.000	120	0.72
		136-213	Late Summer	4.000	120	0.91
		214-258	Fall	2.500	120	0.85
		305-366	Winter	0.500	120	0.49
33000	Wetland, Riverine Perennial	0-79	Early	0.400	90	0.40
		80-110	Spring	2.400	90	0.27
		111-135	Summer	4.000	90	0.27
		136-213	Late Summer	2.400	90	1.22
		214-258	Fall	1.600	90	1.56
		305-366	Winter	0.400	90	0.34

Julian Dates		1-90	91-152	153-274	275-335	335-366
Stage		Winter	Spring	Summer	Fall	Late Fall
Veg Codes	Veg Name	Crop Coefficients (Kc)				
40001, 54001, 39001	Ponderosa, Whitebark-Pine Montane, 10-25% Canopy	0.24	0.37	0.62	0.43	0.24
40002, 54002, 39002	Ponderosa, Whitebark-Pine Montane, 26-50% Canopy	0.31	0.52	0.74	0.62	0.25
40003, 54002, 39003	Ponderosa, Whitebark-Pine Montane, 51-75% Canopy	0.46	0.78	1.11	0.92	0.37
40004, 54004, 39004	Ponderosa, Whitebark-Pine Montane, 76+% Canopy	0.50	0.85	1.20	1.00	0.40
44001, 59001	Lodgepole, 10-25% Canopy	0.22	0.33	0.56	0.39	0.22
44002, 59002	Lodgepole, 26-50% Canopy	0.28	0.47	0.66	0.55	0.22
44003, 59003	Lodgepole, 51-75% Canopy	0.42	0.71	1.00	0.83	0.33
44004, 59004	Lodgepole, 76+% Canopy	0.45	0.77	1.08	0.90	0.36
38001	Western Juniper, 10-25% Canopy	0.24	0.48	0.62	0.28	0.30
38002	Western Juniper, 26-50% Canopy	0.31	0.58	0.74	0.40	0.31
38003	Western Juniper, 51-75% Canopy	0.46	0.88	1.11	0.60	0.46
38004	Western Juniper, 76+% Canopy	0.50	0.95	1.20	0.65	0.50
92000	Sagebrush Steppe, 60-80%	0.20	0.44	0.62	0.24	0.10

## 2.8 Mannings Roughness Coefficient for Overland Flow

The Mannings roughness coefficient "n" was used to represent the roughness of the Sprague River Watershed ground surface (including vegetation) in calculating the overland flow of water from one cell to the next. The larger the Mannings "n" value, the rougher the surface and the more restricted the flow of water, as opposed to a smaller "n" value. The "n" values are based on the type and density in the understory vegetation. One assumption made for this study was that forest canopy densities are inversely related to understory densities; therefore, smaller Mannings "n" values were used for the denser stands of Junipers, Lodgepole, and Ponderosa pine stands, and visa versa. The "n" values listed in the table below were used only for the sheet flow calculations. This sheet flow occurs in the areas outside of the river and stream channels. A Mannings "n" of .035 was used in the river channels to calculate the water depth.

<b>Vegetaion Codes</b>	<b>Vegetation Type</b>	<b>“n” value</b>
40001, 54001, 39001	Ponderosa, Whitebark-Pine Montane, 10-25% Canopy	0.67
40002, 54002, 39002	Ponderosa, Whitebark-Pine Montane, 26-50% Canopy	0.58
40003, 54002, 39003	Ponderosa, Whitebark-Pine Montane, 51-75% Canopy	0.52
40004, 54004, 39004	Ponderosa, Whitebark-Pine Montane, 76% Canopy	0.33
44001, 59001	Lodgepole, 10-25% Canopy	0.67
44002, 59002	Lodgepole, 26-50% Canopy	0.58
44003, 59003	Lodgepole, 51-75% Canopy	0.52
44004, 59004	Lodgepole, 76+% Canopy	0.33
38001	Western Juniper, 10-25% Canopy	0.67
38002	Western Juniper, 26-50% Canopy	0.58
38003	Western Juniper, 51-75% Canopy	0.52
38004	Western Juniper, 76+% Canopy	0.33
92000	Sagebrush Steppe, 60-80%	0.58
21000	Pasture,	0.17
121000	Grass , Shrub	0.13
25000-33000	Wetland	0.10

## 2.9 Soils

The hydrologic cycle is directly influenced by soils and their characteristics. Permeability, saturated hydraulic conductivity, water holding capacity, constricting layers (i.e. hardpans, durapans, and aquatards), slope, and soil depth affect surface runoff, water infiltration, and subsurface movement of water. These parameters, along with a specific soil’s extent and location in the watershed, become a key component of the hydrologic model.

Both NRCS and the United States Forest Service (USFS) have mapped soils in portions of the Sprague River Watershed at various scales. A second order soil survey (SURGO) was completed and published in 1982. This survey, however, only covered the Sprague River Valley and not the forested uplands. Currently, NRCS and USFS are in the process of remapping, updating, and expanding the extent of the second order soil survey for this area. Second order soil surveys that can be used for operational or detailed planning would be ideal for a hydrologic model. Typically, they are mapped at a scale of 1:20,000 with a minimum soil area representation of 1.5 acres.

Preliminary information from the on-going soil survey update was considered for this study; however, final soil correlations and characterization have not yet been completed. Without the finalized information, it was decided not to use preliminary data. And since the published soil survey does not cover the whole watershed, a general soil survey (Fourth Order) was used instead. In some cases, the published SURGO soil survey and preliminary soil survey were consulted for soil differences discovered in the field scale models.

The U.S. General Soil Map<sup>17</sup> used in this study consists of general soil association units. It consists of a broad based inventory of soils and non-soil areas that occur in a repeatable pattern in the landscape and that can be cartographically shown at the scale mapped (1:100,000) with a minimum soil area representation of six acres. The General Soil Map dataset consists of geo-referenced vector digital data and tabular digital data. The soil map units are linked to attributes in the tabular data, which give the proportionate extent of the component soils and their properties. The National Soil Information System (NASIS)<sup>18</sup> was queried to obtain the most current soils information for the predominant soil within each general soil association unit for the Sprague River Watershed. The primary soil attributes required for the MIKE SHE model include soil layer depths, texture, soil moisture at saturation, and saturated hydrologic conductivity.

## **2.10 Topography**

Runoff and infiltration are impacted by slope and aspect (direction of flow). The Digital Terrain Model (DTM) used for the MIKE-SHE input was generated from the USGS 10 meter Digital Elevation Model (DEM) for use at the sub-watershed and full watershed scale. LiDAR data were collected for the Sprague River Valley in November 2004 at 0.5 meter resolution and were provided for this study by the Klamath Tribes. These LiDAR data were used to generate the DTM used for ranch and reach scale model scale simulations.

## **2.11 Bathymetry and Cross-Section Data**

The MIKE SHE model includes channel hydraulics (MIKE 11) which simulates stream water levels and overbank flood events. Stream water levels can impact overland subsurface (inflows to the stream), as well as stream discharge (outflows from the stream) to the adjacent valley bottom lands. Bathymetric data were collected along the Sprague River with a hydroacoustic unit in April and May of 2005 by Max Depth Aquatics. The Bathymetric surface data were then merged to the LiDAR dataset to create a seamless 0.5 meter ESRI grid. Cross-sections for input to the MIKE 11 model were generated from the merged LiDAR and bathymetry dataset.

## 2.12 Flow Data

The flow data used as input for and/or to calibrate and validate the MIKE-SHE model was obtained at the following locations:

- USGS
  - 11501000, Sprague River near Chiloquin, OR (1921-2007).
  - 11499100, Sycan River below Snake Creek near Beatty, OR (1973-2007).
- USBR
  - 11497500, Sprague River near Beatty, OR (1912-2007).
- Graham Mathews and Associates
  - SFSPA, South Fork Sprague River at Picnic Area (2004-2005).
- NRCS
  - Monitoring site 4, Sprague River below Sprague River Bridge (2005-2007).
- Klamath Tribes
  - Bi-weekly flow observations from 2001 to current at multiple sites.

## 2.13 Hydrography

Stream hydrography was based, in general, on a 1:24,000 scale stream layer obtained from USFS. Along the Sprague River Valley, stream centerlines were digitized from the merged LiDAR and bathymetry dataset. This dataset was used to establish the stream network used with the MIKE SHE/MIKE-11 hydrologic models.

## 2.14 Irrigation Documentation

Documentation of irrigation in the Sprague River Watershed included identification of the acres irrigated, the irrigation type (surface-wild flood, surface-controlled, or sprinklers), and the water source (river or well). This information was developed and documented spatially in a GIS database. Other information on water rights, water use, irrigation well depths, and other water management data were gathered from secondary databases or from field monitoring and land owner interviews.

Irrigated pastures were first delineated based on the OWRD spatial point of use database<sup>19</sup> for irrigated water rights. This layer was then further refined by NRCS through the interpretation of digital orthophotography and extensive ground-truthing. The total number of acres identified with irrigation water rights by OWRD and those mapped by NRCS were within five percent of each other. Possible reasons for the disparity include different spatial resolutions, uncertainties in OWRD's water rights database due to the on-going re-adjudication process and mistakes in NRCS's mapping. This study used the 47,998 acres identified and mapped by NRCS. NRCS also identified approximately 4,000 acres of wet meadow as being naturally sub-irrigated.



Attributes were added to denote the irrigation type (wild flood, controlled flood (i.e. gated pipe), or sprinkler) and the irrigation source (stream or well). The OWRD water rights database was used to determine the source. On fields where the OWRD database indicated both a surface and a well source, it was assumed that the ground water was a secondary, supplementary source. On parcels identified by NRCS as irrigated but not covered in OWRD's database, assumptions were made on the source based on the area's proximity to a surface source, owner listed water rights, and local knowledge.

The irrigation type was identified by NRCS from interpretations of digital ortho-imagery, visual survey, and local knowledge. This research indicated that 70 percent of the irrigated lands are surface irrigated, and most (56 percent) are wild flood irrigated. Wild flood irrigation is created by contour ditches where landowners create temporary dams to divert water onto their fields. Fields that are wild flood irrigated typically are not land leveled or smoothed; therefore, wild irrigated fields result in an uneven application of water. Methods for the controlled surface irrigation of fields include border irrigation

and gated pipe. Border irrigated fields are those that have been leveled or smoothed in the past to improve irrigation uniformity; however, most border irrigated fields in the Sprague River Watershed have not been maintained in recent years. A few fields in the Sprague River Valley that had been wild flood irrigated have since been converted to a gated pipe

**Table 9: Irrigation in the Watershed.**

Irrigation Type	Acres	Percent
Surface, Controlled	6,773	14%
Surface, Wild	26,840	56%
Sprinkler	14,386	30%
Total Irrigated	47,999	100%

delivery and application system without any improvements to the irrigated fields (smoothing or leveling). A final method is sprinkler irrigation, which uses a wide array of systems, including big guns, hand lines, wheel lines, and center pivots. Maintenance of sprinklers (gaskets, nozzles, and pumps) was not inventoried in this study.

**Table 10: Irrigation Water Source.**

Irrigation Water Source	Acres	Percent
Surface (streams)	24,474	51%
Ground water (well)	17,879	37%
Both Surface & Well	5,646	12%
Total Irrigated	47,999	100%

Most of the water used for irrigation in the Sprague River Valley is diverted from surface waters. Fifty-one percent of irrigated lands (24,747 acres) have only a surface water source. Thirty-seven percent obtain their irrigation water solely from ground water. Twelve percent of the lands, or 5,646

acres, have both a surface and ground water right. In this case, irrigators normally will use surface waters first and only use ground water to supplement surface sources.

Information was also queried from the OWRD irrigation well logs to determine well locations, drilled depth, yield (gpm), and static water levels, as is represented in the following table.

Irrigation Wells/ OWRD Well Logs	Statistic	Surface Reach Location					
		Below O'Chollis Canyon	Between O'Chollis and Town of Sprague River	Between Town of Sprague River and Beatty Gap	Sycan River Reach between Drewes Road & confluence	Between Beatty Gap and Town of Bly	All Reach Locations
Drilled Depth (ft)	Mean	316	866	438	660	415	496
	Max	722	1,669	1,700	1,168	905	1,700
	Min	125	31	30	140	40	30
Static Water Level (ft)	Mean	40	32	17	10	55	29
	Max	166	77	82	89	206	206
	Min	6	0	0	0	0	0
Water Yield (gpm)	Mean	843	874	1,371	1,055	1,589	1,255
	Max	3,700	2,900	4,000	2,760	4,000	4,000
	Min	50	30	40	100	60	30

This information was used in defining the regional aquifer and depth to the saturated zone in the hydrologic model.

## 2.15 Geology/Geo-Hydrology

An accurate description of the hydro-geologic layers was essential in order to accurately represent ground water in the MIKE SHE model. Volcanic eruptions and the processes of erosion and sedimentation have formed the geology and shaped the geomorphology of the Sprague River Watershed. The surficial geology of the watershed from the oldest to youngest deposits consists of Neogene volcanic and sedimentary rocks that range from middle Miocene (less than 10 million years ago) through Pliocene time (5.3 to 1.8 million years ago). These volcanic rock units encompass a range of compositions from silicic (rhyolitic) to mafic (basaltic). The Miocene- and Pliocene-aged basaltic units are intercalated with a thick sequence of lacustrine and fluvial sedimentary beds (Quaternary sedimentary deposits). These sedimentary units are dominantly bedded siltstone and are currently best exposed in a road cut along Drewes Road, north of the community of Sprague River. The siltstone actually forms the riverbed in many locations through the valley and has provided vertical stability to the low gradient portions of the river. As a result of this stability, the river has meandered slowly back and forth across the valley floor.

The eruption of Mt. Mazama 6,800 years ago blanketed the surrounding landscape with pumice and ash for hundreds of square miles. Extensive upland areas, especially to the north of the Sprague River, were covered with these pyroclastic materials. These deposits consisted primarily of sand to gravel-sized pumice and formed a highly pervious blanket over the former pre-Mazama landscape. For the watershed hydrology, this blanket of Mazama coarse-grained pyroclastic material is very important to the infiltration of snowmelt and rainfall and subsequent recharge of ground water.

In areas such as the Knot Tableland, just north of the river, between the towns of Sprague River and Beatty, this ash and pumice has piled up in drifts and dunes, but in other areas the surface has a biscuit/scabland appearance with the older basaltic volcanic deposits exposed over large areas and the Mazama pumice concentrated in the biscuit areas.

The youngest materials consist of recent alluvial deposits along the Sycan and Sprague rivers and other major tributary creeks. Older alluvial sediments form extensive fan surfaces on the south side of the main Sprague River Valley. Faulting during the last three million years has contributed to the location of volcanic eruptive centers, springs, and compartmentalization of the Sprague River Valley.

Ground water is an important resource in the Upper Klamath Basin, providing much of

<b>Table 12: Estimated Ground Water Discharge to the Sprague River Stream Reaches.</b>	
<b>Stream Reach</b>	<b>Ground water Gains/Losses (cfs)</b>
South Fork Sprague River	24
North Fork Sprague River	92
Upper Sprague River (above Beatty Gap)	52
Lower Sprague River (below Beatty Gap)	150
Upper Sycan River (above marsh)	24
Sycan Marsh	-15
Lower Sycan River (below marsh)	21
Total Estimated Ground water Discharge	348

the inflow to the Upper Klamath Lake. Ground water discharge provides a relatively constant supply of clean, cool water important for fish and wildlife as well as for downstream use for irrigation.

In the Sprague River, the USGS has estimated an average annual ground water discharge to the

river, its tributaries, and its associated springs at approximately 348 cfs. Of this, 150 cfs of ground water is discharged to the Sprague River below Beatty Gap through spring complexes, including the Medicine, Kamkaum, McReady, and Whitehorse springs. Ground water discharge in to the Sprague River accounts for almost 60 percent of the mean annual stream discharge at Chiloquin of 580 cfs from 1922 to 2006.

An estimated 37 percent of the irrigated lands in the Sprague River Watershed are irrigated from wells. With an average water right of three acre-feet per acre for 17,900 acres, this represents a potential ground water discharge from irrigation wells of almost 54,000 acre-feet annually, or 190 cfs during a normal 140-day irrigation season.

The Sprague River Watershed is part of a regional ground water system in the Upper Klamath Basin. Ground water in the Sprague River Watershed generally flows from uplands toward the river and then westerly down the valley toward its confluence with the Williamson River. An unknown quantity of ground water leakage may occur to the south into the Lost River drainage. The USGS has described three basic layers important to the regional ground water system. Permeable late Tertiary to Quaternary volcanic rock underlies the basin. Interbedded with the volcanic rocks are late Tertiary sedimentary rocks and fine-grained sedimentary deposits. The sediments are the youngest stratigraphic unit that includes lake and alluvial deposits along the valley floodplains.

These sediments are generally low in permeability, which can restrict ground water movement.

Two saturated zones were used at different times in the model for this study, one to represent the shallow, perched water table in the Sprague River Valley and the other to represent the deeper, regional aquifer. The shallow aquifer found in the valley influences surface and subsurface return flows to the river while the regional aquifer impacts spring flows and the availability of ground water for irrigation and domestic use. The USGS and the Oregon Department of Water Resources completed a report in 2007 on the ground water hydrology of the Upper Klamath Basin, which includes the Sprague River Watershed.<sup>20</sup> A second report will be forthcoming on results of the USGS's modeling efforts of the regional aquifer using the MODFLOW model. NRCS relied heavily on the USGS's expertise and data to populate the hydro-geologic layers of MIKE SHE.

## **2.16 Water Quality Monitoring and Evaluation (Klamath Tribes/USGS/NRCS)<sup>21</sup>**

The water quality of the Sprague River affects its beneficial uses not only within the valley but also downstream in the Upper Klamath and Agency Lakes. A Total Maximum Daily Load (TMDL) completed by the ODEQ estimated that the Sprague River contributes 26.5 percent of the external loading of phosphorus to the lakes. High nutrients in the lakes promote the growth and decay of algae, which consumes dissolved oxygen to levels detrimental to endangered Lost River and shortnose suckers in the lakes.

The Sprague River itself has water quality issues associated with temperature, dissolved oxygen, pH, nutrients, stream flow, and habitat modification. The ODEQ completed a TMDL for the Sprague River where they assumed that actions to reduce stream temperatures would also solve problems with Dissolved Oxygen (DO) and pH levels. They estimated that 25 percent of the thermal load to the Sprague River is due to human activities that eliminated riparian vegetation, resulting in channel widening and depleted stream base flows. Thermal modeling conducted by the ODEQ predicted that restoring potential vegetation, channel widths, and stream flows would result in 100 percent of the main stem Sprague River stream length and 90 percent of the tributaries, meeting a temperature target of 68 degrees Fahrenheit.

The USGS conducted a preliminary assessment of existing water quality data in a study jointly funded by the USGS, the Klamath Tribes, and NRCS. Stream water quality samples collected by the tribes since 2001 represent the main database, supplemented with some shallow ground water samples gathered by NRCS in 2005-2006. The main purpose of this USGS study was to develop a general understanding of the nutrient dynamics in the watershed. Some of their findings state that:

- The Total Phosphorus (TP) concentrations were at or near the documented background levels of 0.063 mg/l suggested by Kann and Walker (1999).
- TP transport was greatest during the spring due to higher spring runoff along with associated erosion and channel scouring.

- There was no decline in TP concentrations going downstream during the warm irrigation season, plus there was considerable aquatic plant growth, indicating ongoing input of phosphorus to the river.
- The soluble reactive phosphorus (SRP) to TP ratio generally was greater than 0.5, indicating there is more dissolved P than particulate P.
- Dissolved inorganic nitrogen (DIN, the sum of ammonia, nitrite, and nitrate) was at relatively low concentrations and declined from winter through the irrigation season, indicating plant uptake.
- DIN:SRP (the ratio of biologically available N to biologically available P) is less than 7:1, which indicates aquatic growth in the system is limited more by N than P.

These findings point to the importance of understanding a watershed's hydrology in order to determine the effects that management practices may have on water quality. For example, actions that:

- Increase low summer base flows would lower stream temperatures;
- Attenuate spring flood flows would reduce erosion, sediment, and associated particulate phosphorus;
- Reduce surface tail water and subsurface drainage return flows would also decrease loading of dissolved nitrogen (DIN) and phosphorus (SRP); and
- Collectively reduce aquatic plant growth would improve dissolved oxygen and pH levels.

And, finally, the USGS recommended that, "While these existing data provide a good general understanding of nutrients in the basin, more focused study would provide the specific information necessary to understand the degree to which different land-use and water-management practices affect stream chemistry."<sup>21</sup>

### 3. Conservation Effects

The MIKE SHE model was used to simulate the conservation effects on the hydrologic budget in the Sprague River Valley for irrigated grazing lands, juniper removal, and forest thinning. In addition, based on the USGS study of the watershed nutrient cycle, along with a better understanding of the watershed's hydrologic processes, inferences were made as to the potential water quality impacts. Lastly, a study by the University of Oregon, partially funded with NRCS CEAP funds, provided observations on conservation effects from improved riparian area management.

#### 3.1 Irrigated Grazing Lands

Many scientists and landowners view the use of water for irrigation as a significant resource issue in the Klamath Basin that has created problems involving water quality, fish habitat, and wildlife, as well as with downstream irrigators. Some conservationists promote practices that will improve irrigation application efficiency, such as conversion from surface irrigation to sprinklers in order to conserve water.

In the Sprague River Watershed, which is similar to many other watersheds in the semi-arid west, cattle ranches with irrigated pastures lie along the river valley bottom. There are no organized irrigation districts or large storage reservoirs. Each rancher either diverts water from the free-flowing river or pumps from deep, ground water reserves. Irrigation occurs near the river and not far from the point of diversion. In the Sprague River Valley, most irrigation is termed *wild flood*. In this type of irrigation, a series of contour ditches distribute water to release points from where water inundates and ponds individual fields. Typically, ranchers in the Sprague River Watershed do not level or smooth their fields, so the uniformity of water application varies with the natural roughness of the alluvial valley bottom. Excess water either flows overland or seeps through the subsurface back toward the river. In this setting, the impact of different irrigation practices on stream flows, ground water levels, water quality, and forage production are not self-evident.

This CEAP study used the MIKE SHE hydrologic model to simulate the entire land phase of the hydrologic cycle. MIKE SHE, a dynamic, physical process and fully distributed model, estimates the amount and timing of all parts of the hydrologic cycle, including evaporation, transpiration, infiltration, soil moisture levels, overland flow, ponding, and subsurface drainage. It also accounts for interactions between ground and surface waters. The model facilitated our understanding of all aspects of hydrologic change in the valley resulting from different irrigation management scenarios without the need to spend years and significant amounts of money on monitoring and measuring their effects.

With computer simulation models, there are tradeoffs between resolution and computation time. The number of grid cells used to represent the landscape directly affects the resolution and computational time needed to run MIKE SHE. The following

table displays the landscape scale, cell size, and cell numbers determined to be appropriate for the Sprague River Watershed.

<b>Table 13: Modeling Cell Sizes.</b>			
<b>Landscape</b>	<b>Area (acres)</b>	<b>Number of Cells</b>	<b>Cell Size (meters)</b>
Individual Ranch/Field	~500	28,000	10
Irrigated Valley Reach	~40,000	35,000	100
Sprague River Watershed	~1,000,000	4,500	1000

MIKE SHE includes a number of optional computer simulation routines for connecting surface hydrology with channel hydraulics, ground water hydrology, or irrigation routines. Adding numerical complexity to the model, however, increases computation time. The longer the time period (months and years) and the shorter the time step (hours and days) further adds to the number of computations and time model simulations take. The availability of data for the model calibration and validation also can help determine the appropriate model scale and numerical complexity. For example, long-term, historic stream flow data are appropriate to calibrate watershed and sub-watershed models. On the other hand, only a few years of data on soil moisture content and water table levels may be relevant at the site scale (farm or field).

For these reasons, this study simulated hydrologic effects at various scales. Model routines were calibrated and validated at the appropriate scales. Doing so improved the use of the model at each scale. For instance, once the model was calibrated to simulate irrigation at the field scale, it could also validate its use at the sub-watershed or watershed scales. Conversely, if the model were calibrated at the watershed scale to match historic stream flows and ground water levels accurately, it would improve confidence in using the model at finer scales to simulate the interactions of surface and ground water from activities such as ground water pumping.

Appropriate questions at each scale include the following:

Ranch/Field Scale

1. How well does the model calibrate to field collected data on soil moisture and shallow water table levels or AgriMet measured evapotranspiration?
2. Do different irrigation methods and levels of management change irrigation efficiencies, the amounts of evapotranspiration, or runoff?
3. How does the level of grazing management change crop water requirements?
4. How much does the uniformity of irrigation water application change with different irrigation methods?
5. What are the amounts and timing of subsurface drainage and overland return flows to the river as associated with different irrigation alternatives?
6. What are the potential changes in the stream's water quality as they relate to different irrigation alternatives?

### Valley Reach Scale

1. What are the seasonal effects on stream levels and flow from changing the current irrigation water management to higher levels?
2. What are the seasonal effects on stream levels and flow if all irrigation water were diverted from the river (none withdrawn from the aquifer)?
3. What are the seasonal effects on stream flow if all water were supplied from the regional aquifer?
4. How might different irrigation management alternatives affect the mass balance of nutrients reaching the river or of thermal conditions affecting the stream's temperature?

Several important questions can also be asked about the entire watershed scale, for example:

### Watershed Scale

1. What impacts does ground water pumping have on surface flows and ground water levels?
2. How much does ground water supplement stream flows?
3. Will increased ground water use reduce ground water discharge?

The USGS regional ground water study and model (MODFLOW) will address these watershed scale questions. The USGS has extensive experience on ground water hydrology; thus, NRCS has chosen to leave these questions to them. NRCS is working closely with the USGS to share and compare information to complement these efforts.

## **3.2 Irrigated Ranch/Field Scale**

Ranch scale monitoring for soil moisture, shallow water table levels, stream flow, and precipitation began during the summer of 2005 and continued through the spring of 2008 on four ranches along the Sprague River Valley. These ranches are similar in that they



have irrigated pastures that are sometimes also used for hay production. Irrigation varies from wild flood, to gated pipe, to border irrigation, to sprinklers (wheel lines and center pivots). All soils in the valley are mapped as part of the Onko-Dilman-Klamath soil complex, though some obvious differences exist in certain fields.

**Figure 13. Photo Showing the Downloading Monitoring Data.**



Two ranches were modeled, analyzed, and compared in an attempt to answer the scale appropriate questions for this report. Data collected from two additional ranches were merely intended to add to the researchers' familiarity with irrigation practices and their effects on the water budget in the area. The table below describes the basic data collected on all four ranches. Ranches 1 and 2 were modeled and Ranches 3 and 4 provided supporting information.

<b>Table 14: Description of NRCS Field Monitoring Sites on Four Sprague River Ranches.</b>			
<b>Ranch</b>	<b>Description</b>	<b>Notes</b>	<b>Model Uses</b>
Ranch 1	580 acres total, 100 acres irrigated, 480 acres wetland/riparian.	Not irrigated last several years, WRP easement, CREP riparian.	1. Control-Model calibration. 2. Border strip flood irrigation. 3. Alfalfa risers/buried pipe delivery irrigation with border strips.
Ranch 2	500 acres total, 360 acres irrigated pasture.	Irrigated pasture, cattle grazing, riparian fencing.	1. Model-Validation. 2. Wild flood irrigation. 3. Gated Pipe irrigation. 4. Wheel line sprinklers.
Ranch 3	550 acres, all irrigated and grazed with 150 of these acres hayed.	Irrigated pasture, hay, and cattle grazing.	1. Data comparison of water table, soil moisture, and stream flow responses.
Ranch 4	450 acres, 350 acres irrigated pasture.	Irrigated pasture, cattle grazing, riparian fencing.	1. Data comparison of water table, soil moisture, and stream flow responses.

Assumptions used in the ranch scale models state that:

1. The thick sequence of lacustrine and fluvial sedimentary beds which underlies most of the Sprague River Valley acts as an aquatard, perching water above shallow depths (10 to 15 feet or less).
2. The irrigation season starts June 1<sup>st</sup> and extends to October 20<sup>th</sup>.
3. Two levels of grazing management were defined for this study as:
  - Fair forage management, which maintains a stubble height of two inches or less throughout the summer.
  - Good forage management, which maintains a stubble height of three inches or more.

### 3.2.1 Description of Irrigated Ranch 1

Ranch 1 (schematically depicted on the next page) was used primarily as a control for model calibration since it was not irrigated during the three years in which monitoring data was collected. Irrigation management scenarios were simulated based on planned changes in irrigation management anticipated by the landowners.

General Description:

- This ranch occupies about 580 acres within a large bend in the river.
- No active irrigation has taken place for several years.

- The ranch lies in the southern part of the irrigated valley.
- Previously, about 400 acres were wild flood irrigated, 100 acres border irrigated, and the rest consisted of riparian areas and levees.
- The entire property was used for cattle grazing, and the 100-acre border irrigated field was hayed.
- In the past, the 100-acre hay field was broken into a series of 85 leveled, bermed borders, and flood irrigated.
- The open ditch delivery system to the 100-acre hay field was converted in 2007 to buried mainlines with alfalfa risers to facilitate irrigation water management.
- The rest of the property, approximately 480 acres, is currently under wetland and riparian restoration.
- A levy separates and isolates almost the entire property from the river.
- The 100-acre hayfield consists predominately of well-drained Lobert soils, and the rest of the property lies on poorly drained Klamath soils.

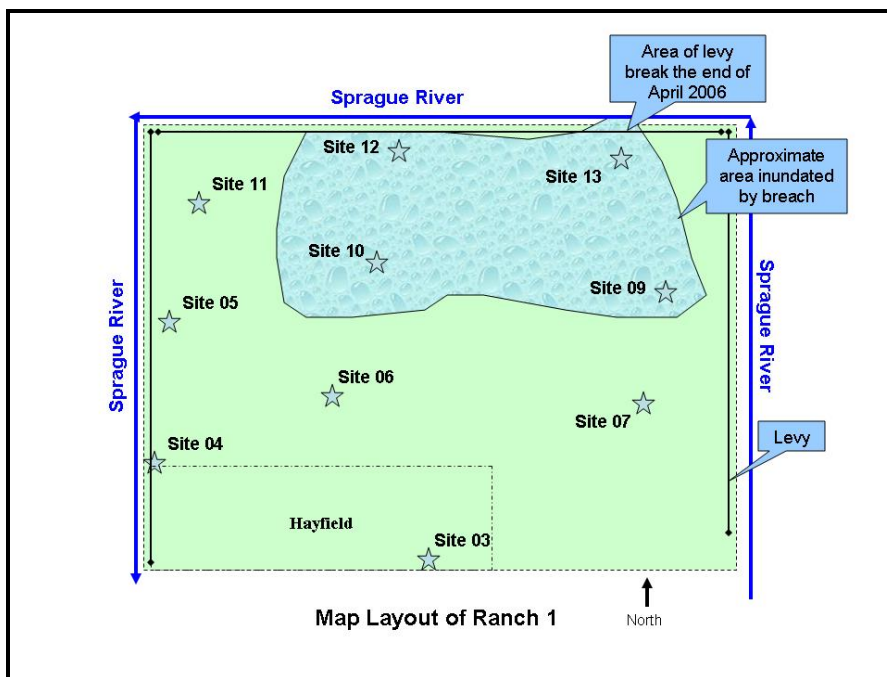


Figure 14. Schematic Layout of Ranch 1.

For the CEAP study, thirteen sites were installed to monitor the shallow water tables and soil moisture levels from the summer of 2005 through the spring of 2008. The observed water table and soil moisture levels, being impacted only by precipitation and river levels, resulted in this property being an excellent control for calibrating the MIKE SHE model as the data was not affected by added irrigation water. The following charts show the observed soil moisture at one soil moisture site and six shallow water table monitoring sites.

Problems with the soil moisture probe (e.g. non-continuous readings) resulted in the collection of only one year of usable data. Nevertheless, the model seemed to adequately account for soil moisture. Note the similar decline in soil moisture that was both

observed and predicted, going from saturation during the 2005-2006 winter into the summer of 2006.

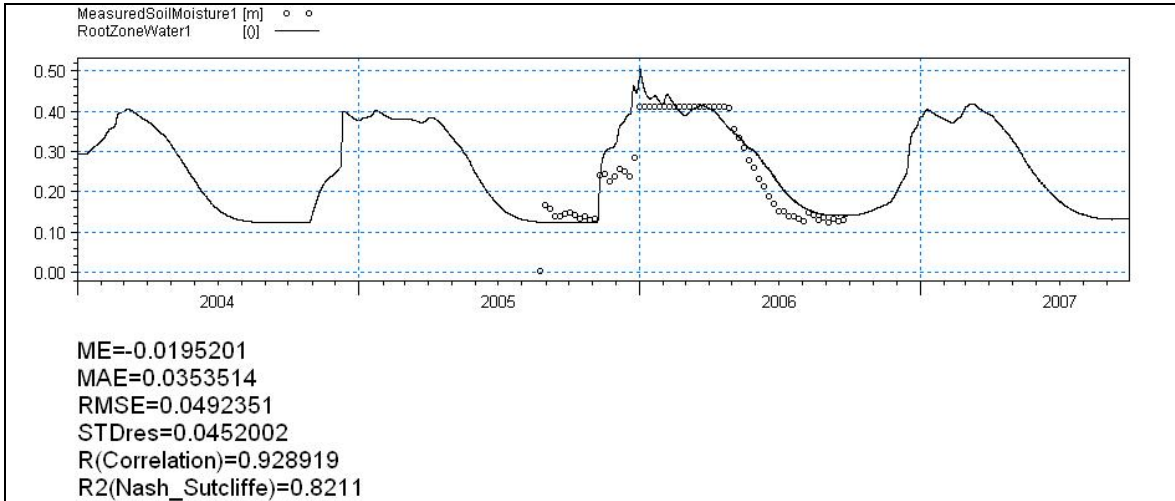


Figure 15. Soil Moisture (%) at Site 6.

The following charts compare the observed and simulated shallow water table elevations at six locations. The Nash-Sutcliffe<sup>22</sup> statistic at ranch 1 varies from a high of 0.92 to a low of 0.39, demonstrating a good statistical fit. The main calibration parameters for the model were the soil's hydraulic conductivity and subsurface inflow into the field.

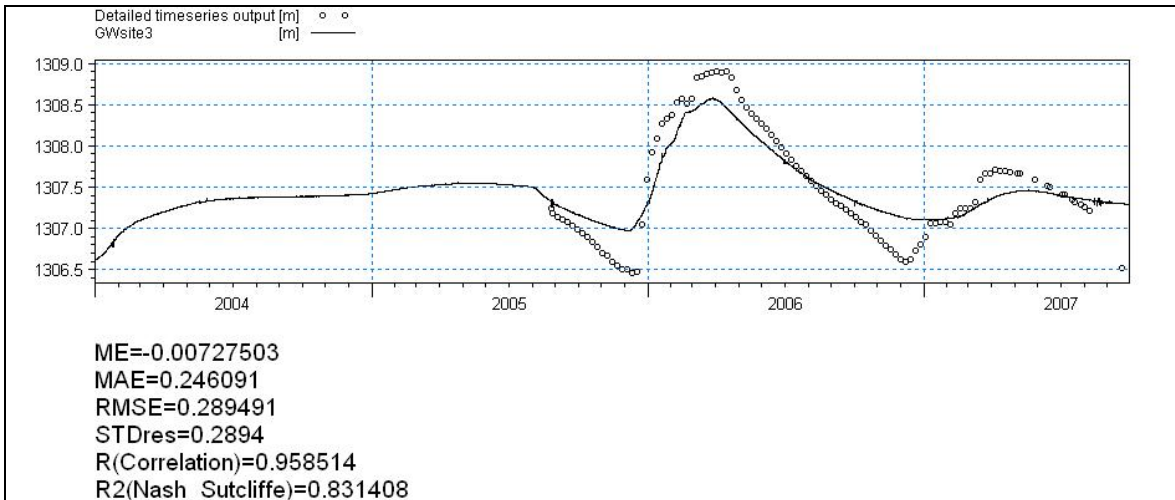


Figure 16. Ground Water Elevations (Meters) at Site 3.

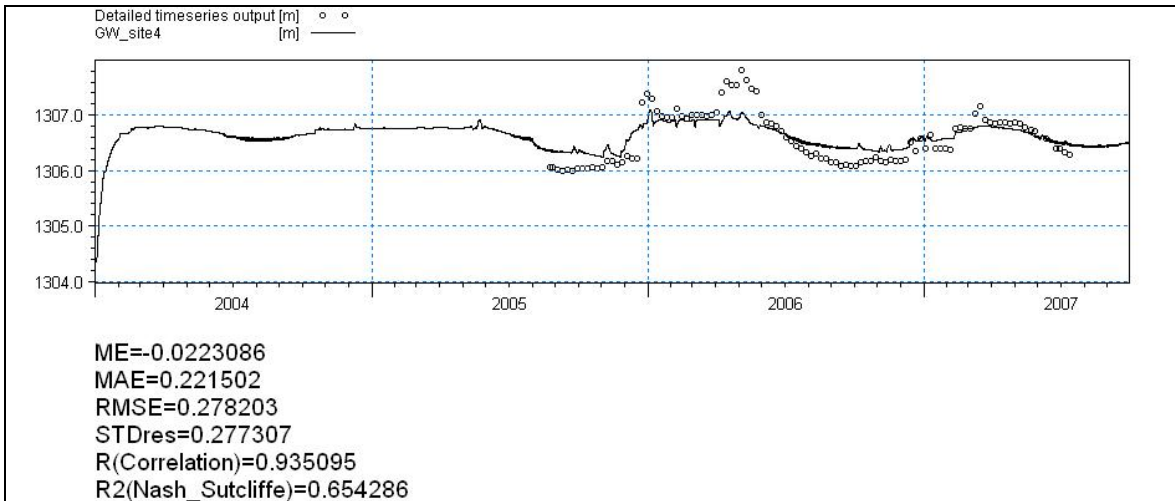


Figure 17. Ground Water Elevations (Meters) at Site 4.

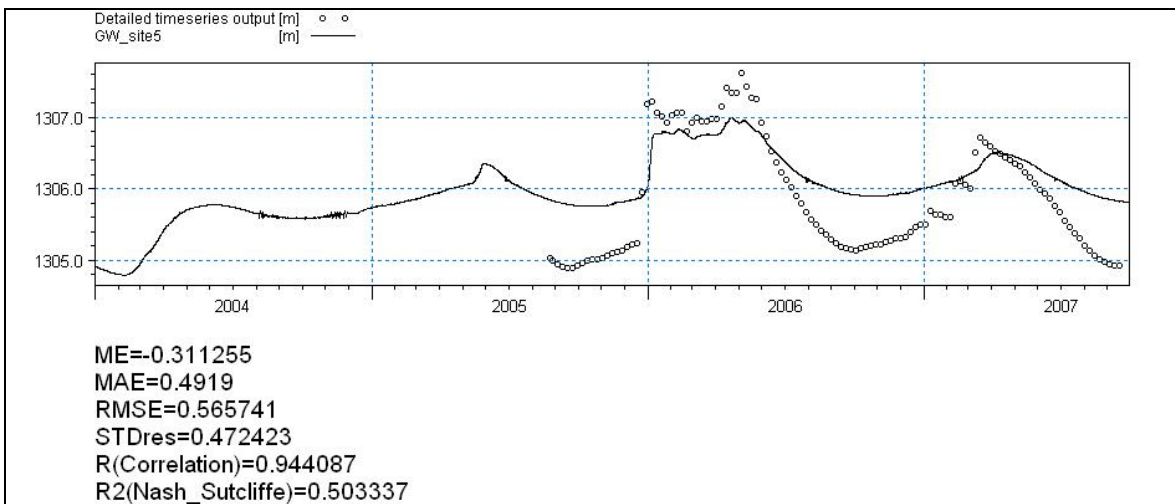


Figure 18. Ground Water Elevations (Meters) at Site 5.

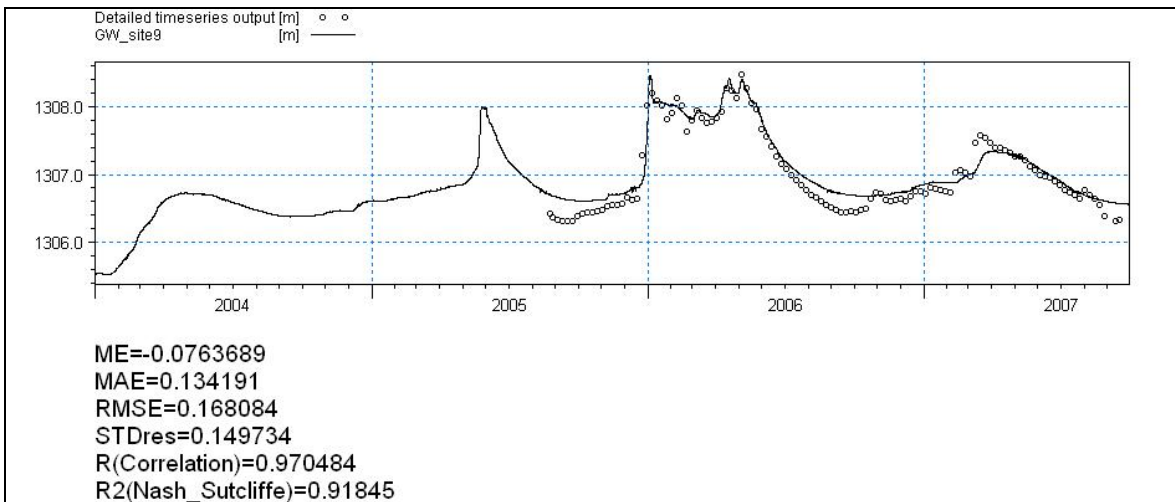


Figure 19. Ground Water Elevations (Meters) at Site 9.

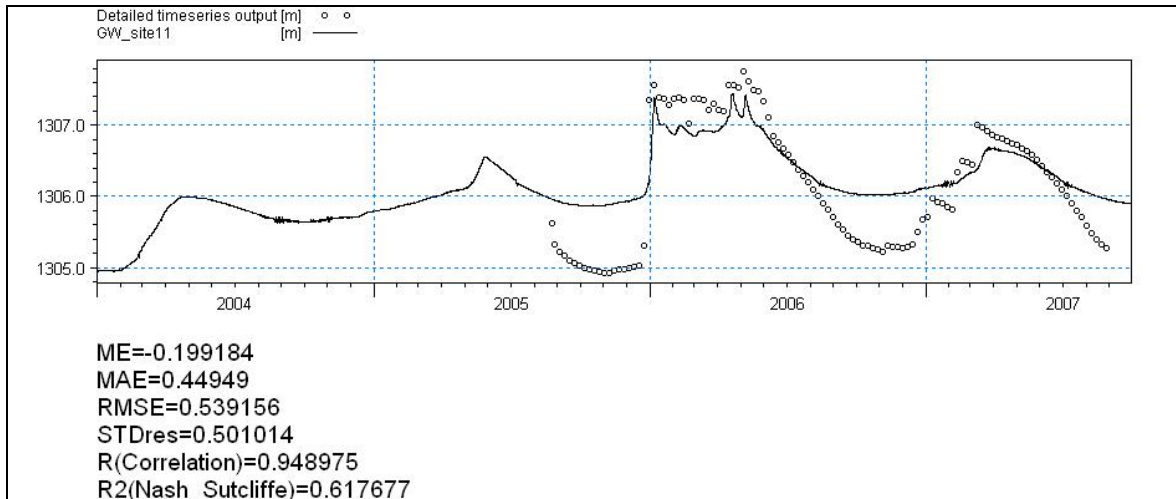


Figure 20. Ground Water Elevations (Meters) at Site 11.

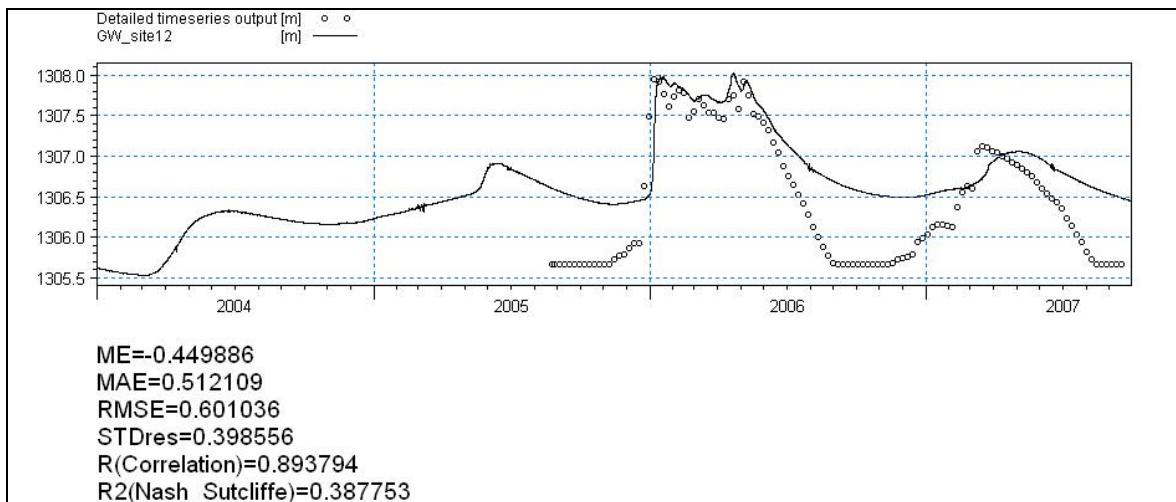


Figure 21. Ground Water Elevations (Meters) at Site 12.

### 3.2.2 Irrigated Ranch 1 Monitoring Observations

The plots in Figure 23 demonstrate several observations:

- The shallow water table gradient flows from the south (site 3) to the north (sites 9 and 13) and towards the river (site 4).
- The well at site 4 located 15 feet from the river, directly reflects changes in river levels.
- Wells at site 9 (300 feet from the river) and site 13 (500 feet from the river) also appear to be somewhat influenced by the river.
- Site 3 (1,200 feet from river), besides exhibiting similar seasonal variation, does not respond to individual peaks and troughs in river levels.

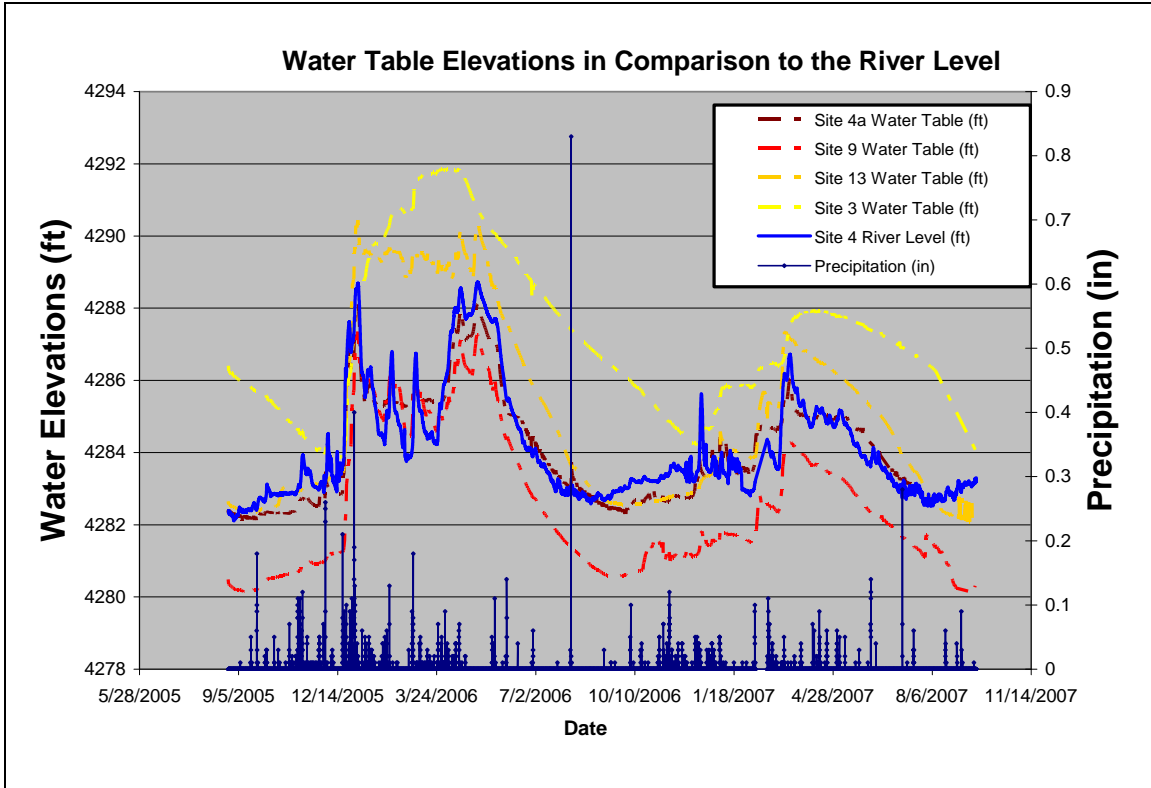
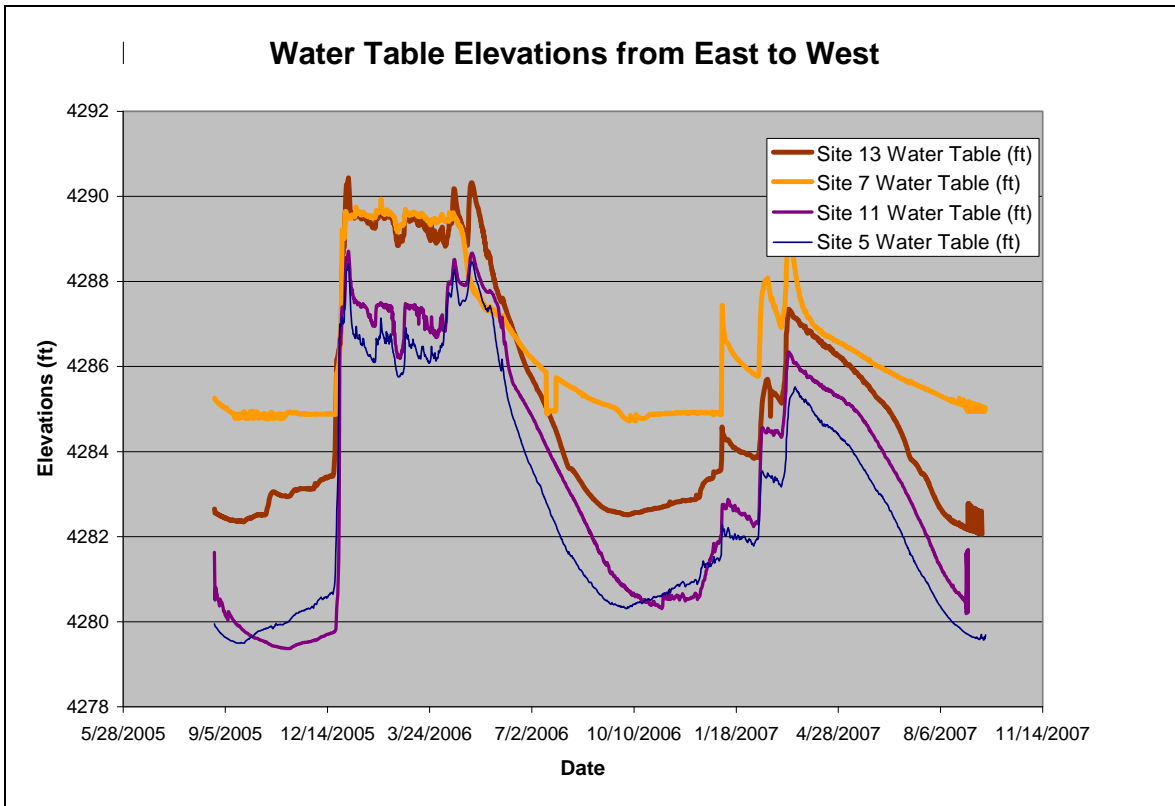


Figure 22. Water Table Elevations in Comparison to River Levels.

Figure 24 below compares shallow water table elevations for sites 7 and 13 (on the east side of the property) to sites 5 and 11 (to the west). Here, the shallow water table gradient slopes from the east to west are in a down river direction. From figures 1 and 2, it can be concluded that shallow ground water flows both from the south and east.



**Figure 23. Water Table Elevations From East to West.**

About 400 acres of this property is scheduled for wetland restoration through the Wetland Reserve Program (WRP). Currently, levies on this property interfere with wetland hydrology. In general, a river connected to its floodplain benefits wetland hydrology. These benefits include the reduction of irrigation water requirements at certain times of the year, wetland and riparian habitat restoration, and storage of water in the floodplain that could potentially attenuate the river discharge hydrograph.

During the spring runoff at the end of April 2006, the property's levy failed near site 13, allowing a portion of the property to be flooded. Of particular interest is what can be observed in the monitoring data at sites where the flooding occurred compared to those where it did not (see Figures 25 and 26 below). This property is currently in the design phase for restoring wetland hydrology. One of the alternatives suggested was to breach the levy. Analyzing the soil moisture and ground water levels recorded immediately after this levy failure provided a brief glimpse into what effects the restoration activities might have. This information can now be used to assist in the design of this WRP project.

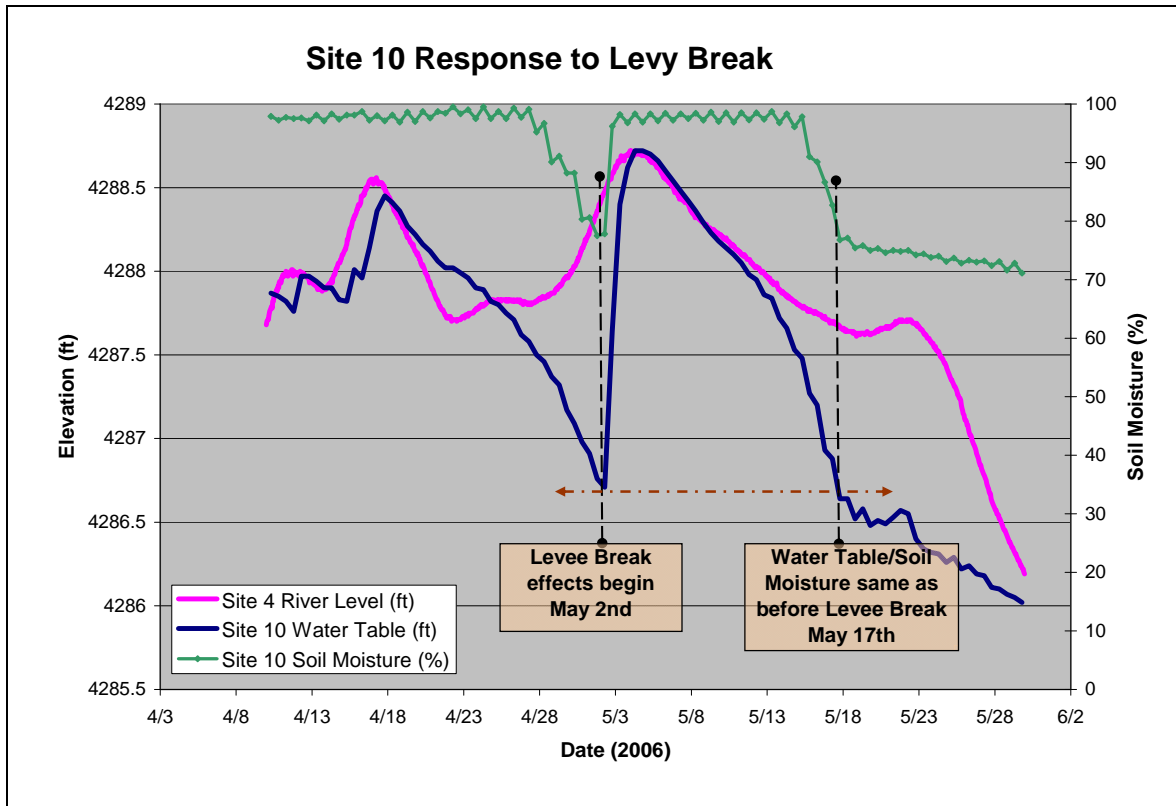


Figure 24. Site 10 Response to Levy Break.

The breach of the levy occurred near site 13 (see Schematic Layout of Ranch 1) and allowed a large, low-lying portion of the property between sites 10 and 13 to be flooded. The soil moisture and shallow ground water sensors at site 10 showed a direct response to this flood event about 2 days after the levy breach. As expected, the soil moisture returned to 100 percent because the area was inundated. The shallow ground water, which had been declining below the surface, also spiked, indicating that the soil column filled with water, allowing water to be stored for a longer period of time. It took about 15 days for both the water table and soil moisture levels to return to those levels experienced before the breach.

Figure 26, below, shows a similar response at site 13, the nearest site to the levy breach. Soil moisture was not measured at site 13, but shallow ground water levels started rising abruptly on April 30<sup>th</sup> and did not return to pre-breach levels until 18 days later on May 17<sup>th</sup>.

Site 6, which lies in an area that was not inundated, also showed a response at the same time as the flooding occurred. Site 6 is over 700 yards away from the levy that failed. Prior to the breach, the soil moisture sensor at this site had recorded declining moisture at an average rate of 3 percent every 12 hours. For 12 days after the breach, the sensor maintained relatively constant moisture content. The ground water sensor at site 6, which was recording water levels below the surface, showed a similar attenuation in the water level for about 12 days.



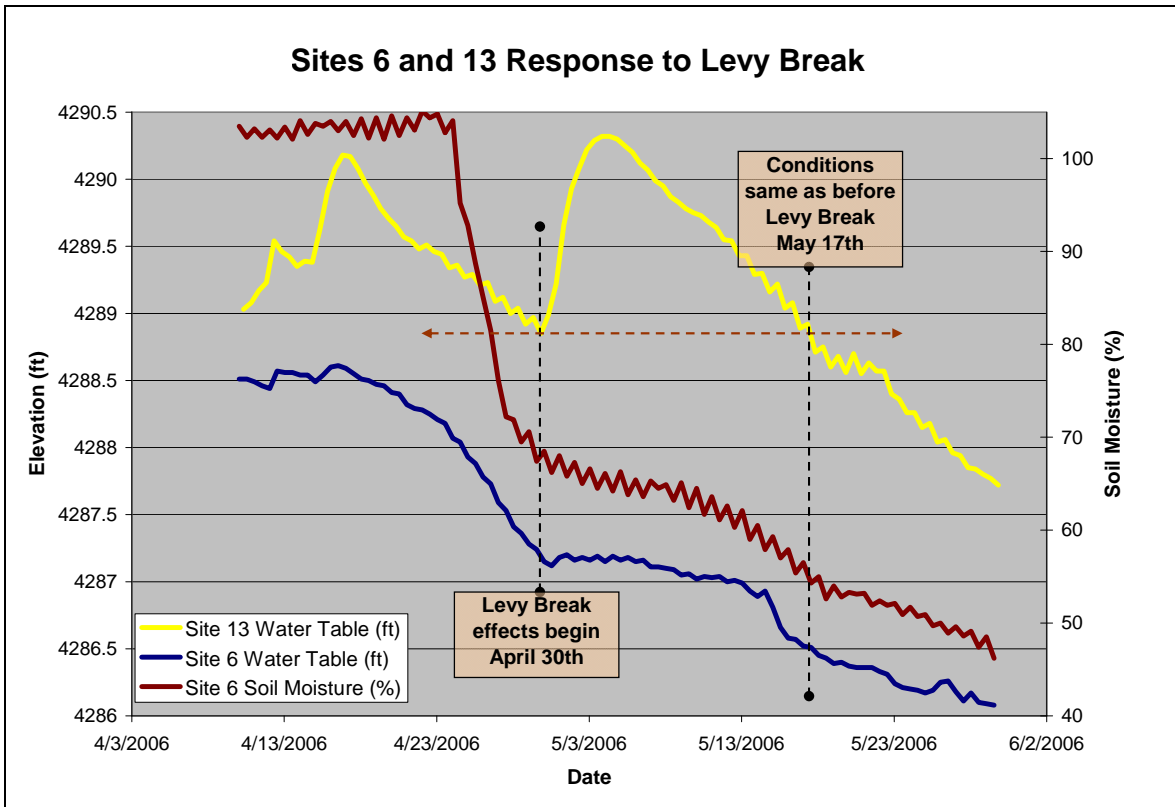


Figure 25. Sites 6 and 13 Response to Levy Break.

Together, these measurements indicate that the hydro period to support the growth of hydrophytic vegetation could be increased by two weeks, or longer, if the valley bottom were reconnected to the river.

A limited number of water quality samples were also obtained from shallow wells on this ranch and the adjacent river. These samples showed that nutrient levels in the shallow ground water were generally several times higher in concentration than in the river.

<b>Table 15: Water Quality Results from Limited Sample on Ranch 1.</b>						
<b>Sample Site</b>	<b>No. of Samples P</b>	<b>Total Phosphorus mg/l</b>	<b>Ratio of TP Site to TP Stream</b>	<b>No. of Samples N</b>	<b>Total Nitrogen mg/l</b>	<b>Ratio of TN Site to TN Stream</b>
Stream	5	0.0832	1.00	2	0.5735	1.00
Well	1	0.4660	5.60	1	0.5320	0.93
Well	2	0.5555	6.68	n/a	n/a	n/a
Well	3	0.4957	5.96	1	1.6700	2.91
Well	3	0.4724	5.68	1	1.8500	3.23
Well	3	0.2030	2.44	1	1.2900	2.25

### 3.2.3 Simulation of Irrigation Management Scenarios for Ranch 1

Three management scenarios were evaluated and compared on ranch 1, shown below.

<b>Scenario</b>	<b>Irrigation System</b>	<b>Diversion Rate (gpm)</b>	<b>Level of Grazing Management</b>
1	No Irrigation	None	No Grazing
2	Border Strips with open ditch	2,000	Low
3	Border Strips with pipeline & alfalfa risers	2,000	High

The MIKE SHE model was calibrated at the field scale using observed water table and soil moisture levels best representing the “No Irrigation” scenario on ranch 1. Before running simulations on ranch 1, researchers validated the field scale MIKE SHE model using a wild flood irrigation scenario that closely resembled actual conditions observed on ranch 2 (Section 3.2.6).

In the past, the hayfield was divided into 85 strip borders that were supplied with water through an open ditch delivery system. With this type of irrigation, each strip is bermed and gently graded to slope from the delivery ditch to the end of the strip. Each strip is then flooded until water reaches the end of the strip. Over the course of the irrigation season, each strip border would be flooded three or four times. This method, when using well-graded strips between berms or bungs, aids in distributing water evenly across the field. However, improperly graded or maintained grades and berms make it difficult to irrigate each strip adequately without applying excess water.

During the study, it did not appear that this particular field had been leveled or smoothed for quite some time. Cattle grazing, frost heaves, and other disturbances had altered the topography. Based on existing topography obtained from LiDAR elevations, the fields were no longer uniformly sloped. There were also high spots and places where berms, along the border strips, had been damaged or eliminated (trampled by livestock or machinery).

While this hayfield had not been irrigated for several years, the landowner converted the delivery system in 2007 from an open ditch to buried pipelines with alfalfa valves. Buried pipelines with alfalfa risers should reduce conveyance losses and provide the irrigator more control at the point of application onto the strips. The MIKE SHE model simulations assumed no re-grading of the slopes or repair to the berms. With open ditch delivery, each border strip is irrigated four times an irrigation season with long sets whereas, with alfalfa valves, each strip is irrigated eight times with shorter sets.

The results in the table below show very little difference between the two scenarios. However, more transpiration did occur with scenario 3 (alfalfa valves). The difference is probably due to more frequent irrigations facilitated by the alfalfa valves, which resulted

in the soil moisture levels remaining between wilting point and field capacity for a higher percentage of the season.

**Table 17: Ranch 1 Simulation Results – Part A.**

Scenario	Average Annual Values (Water years 10/2004 through 9/2007)							
	Prec (mm)	Irrigation (mm)	Total Water (mm)	Total ET (mm)	Total Transpiration (mm)	Total Evap (mm)	ET/ Total Water (%)	Trans/ Total Water (%)
1. No Irrigation	354	0	354	339	225	113	96%	64%
2. Open Ditch & Borders, 2000 gpm	355	901	1,255	773	486	287	62%	39%
3. Alfalfa Risers & Borders, 2000 gpm	354	908	1,263	776	519	257	61%	41%

Scenario 3 shows less loss of water due to evaporation than scenario 2. This is due to the same seasonal amount of water (~900 mm) being applied through smaller, more frequent applications (eight irrigations versus four). A scenario that included re-grading the border strip and re-establishing the berms was not run. If it had been, it likely would have reflected a more uniform application of water with a corresponding reduction in the quantity of water required to flood each border strip.

The following table shows the amount of outflow that occurred from this property into the adjacent river. This includes both overland (surface runoff) and subsurface (shallow ground water discharge) outflows. Two important observations from this data include:

1. With both irrigated scenarios, almost 50 percent of the total annual outflow occurred during the irrigation season.
2. Of the total outflow, regardless of whether it transpired during the water year or the irrigation season, around 60 percent was derived from subsurface runoff and 40 percent from overland runoff.

**Table 18: Ranch 1 Simulation Results – Part B.**

Scenario	Average Annual Water Year			Average Irrigation season			Irrigation Season Outflow / Average Annual (%)
	Over land out-flow (mm)	Sub-surface outflow (mm)	Total out-flow (mm)	Over land out-flow (mm)	Sub surface outflow (mm)	Total out-flow (mm)	
1. No Irrigation	15	73	88	2	0	2	2%
2. Open Ditch & Borders, 2000 gpm	287	369	656	139	175	314	48%
3. Alfalfa Risers & Borders, 2000 gpm	151	290	441	75	127	202	46%

Another method to understand the timing of irrigation return flows was to calculate the percent of excess water above evapotranspiration that returned to the river during the 135 day irrigation season. For scenario 2 and 3 the percent excess water returned to the river were 97 and 69 percent, respectively. In scenario 3 less water was returned during the irrigation season because the more frequent irrigations encouraged greater infiltration and less surface runoff. That meant a higher percentage of the excess water was moving through the subsurface than in scenario 2.

**Table 19: Ranch 1 Simulation Results – Part C.**

Scenario	Average Values During Irrigation season					
	Total Water Applied as Precipitation or thru Irrigation (mm)	Total Inflow from Off the Property (mm)	Total Evapotranspiration (mm)	Excess Water over above ET (mm)	Total Overland and Subsurface flow off Property (mm)	Percent of Excess Water Returned to River (mm)
2. Open Ditch & Borders, 2000 gpm	936	56	670	323	314	97%
3. Alfalfa Risers & Borders, 2000 gpm	971	5	682	294	202	69%

Based on the hydrology and the available water quality data, these outflows imply two potential water quality impacts:

- Stream temperature – since most return flow (~60 percent) originated from shallow ground water discharge, outflow from this property should have an overall cooling effect on stream temperatures.
- Nutrients – the shallow ground water appeared to have a higher concentration of phosphorus and nitrogen than the river itself; therefore, any shallow ground water discharge may increase the stream nutrient levels.

The difference between the quantity of water diverted for irrigation and the quantity of

**Table 20: River Water Balance During Irrigation Season.**

Scenario	Irrigation Water Diverted from River (mm/acre)	Total Outflow Return to River (mm/acre)	Net Water Loss from River (mm/acre)
2. Open Ditch & Borders, 2000 gpm	851	314	538
3. Alfalfa Risers & Borders, 2000 gpm	886	202	684

excess water returned via overland or subsurface flow estimates the net water loss from the river during the irrigation season for the two scenarios. Bermed irrigation borders tend to slow

overland flow and encourage infiltration. Scenario 3 actually has the greatest impact on river flow. Over a 135-day irrigation season on this 100-acre hayfield, the level of loss equates to a reduction of 0.7 to 0.9 cfs in the river for scenarios 2 and 3, respectively.

### 3.2.4 Description of Irrigated Ranch 2

Ranch 2 represented a typical, irrigated ranch within the Sprague River Valley. Besides current conditions, several irrigation management scenarios, along with two different levels of forage management, were simulated using the MIKE SHE model.

#### General Description:

- This ranch is about 500 acres, with 360 actively irrigated.
- It lies north of the river in the western part of the irrigated valley.
- The land is used for irrigated pasture and is stocked with about 300 cow-calf pairs.
- Most cattle are brought onto the property in mid-April and taken off in early November.
- Forage management is fair, with stubble heights of one to two inches.
- Sedges and rushes dominate the vegetation in the lower-lying areas of the pastures.
- Irrigation, depending on spring precipitation, usually starts on the first of June and continues to mid-October.
- All water is pumped from the river into an irrigation delivery system (pipes and open ditches).
- Water is applied via wild flood irrigation through a series of contour ditches.
- The fields have not been leveled or smoothed.
- During the summer of 2006, one field was converted to a gated pipe delivery and application system.
- Poorly drained Klamath soils dominate the irrigated area.

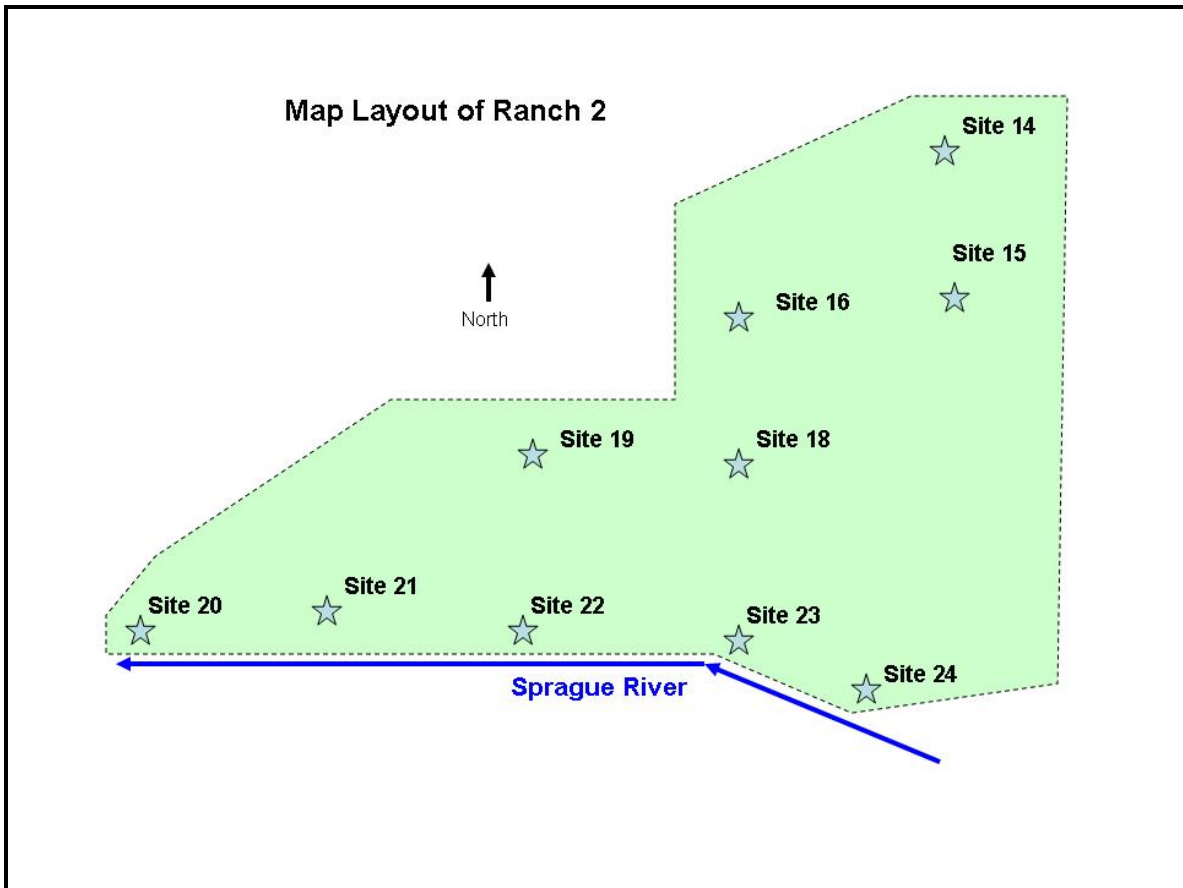
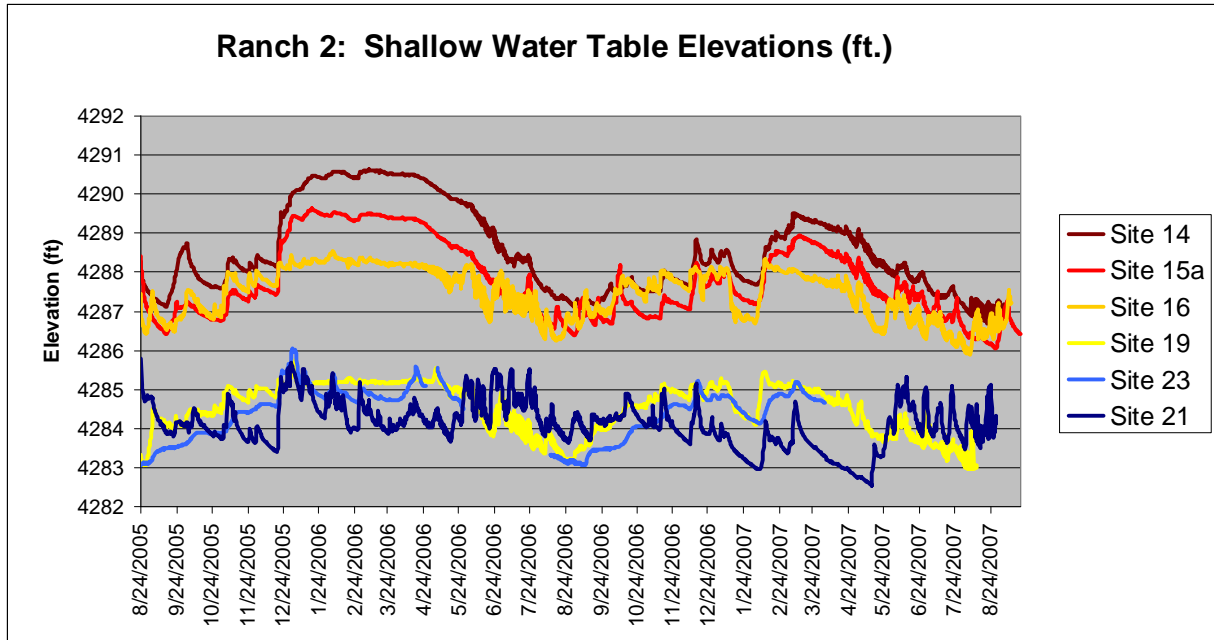


Figure 26. Ranch 2 Schematic Layout.

### 3.2.5 Irrigated Ranch 2 Monitoring Observations

NRCS established 11 sites on this ranch to monitor shallow water table levels and soil moisture within the rooting zone of the pasture grasses. The data collected cover three irrigation seasons starting the summer of 2005 and continuing through the spring of 2008. NRCS also collected limited water quality samples during the summers of 2005 and 2006 from the river, irrigation delivery ditch, shallow ground water, seeps, and surface runoff. Samples were analyzed for nutrients at the Klamath Tribes water quality laboratory.



**Figure 27. Ranch 2 Shallow Water Table Elevations (ft.).**

The wells in the above chart start with well 14, the farthest from the river in the northeast corner of this irrigated area. Site 21 is the farthest from 14, located in the southwestern part of the fields. Sites 14, 15, 16, and 19 demonstrate similar patterns with regards to the timing of winter-spring precipitation and summer-fall irrigation. At sites 21 and 23, however, there appears to be another factor influencing water levels in addition to precipitation and irrigation. The contour hydraulic head drops consistently from the northeast to the southwest with about a 6 foot drop in water table elevation from site 14 to site 21. This corresponds to the approximate five-foot drop in ground elevation from site 14 to 21, suggesting a relatively consistent depth in the soils to an impermeable layer (siltstone) that perches water across these fields.

The shallow water table at site 22, which is located 140 feet from the riverbank, varies according to corresponding changes in river levels. The well at site 21 (270 feet from the river) also shows some response to changes in the river, but less than site 22. The data from well 19 correlates more to the timing of irrigation, as discussed previously, but it does report some spikes that correspond to high river flows during the winter. Well 19 is located over 700 feet from the river.

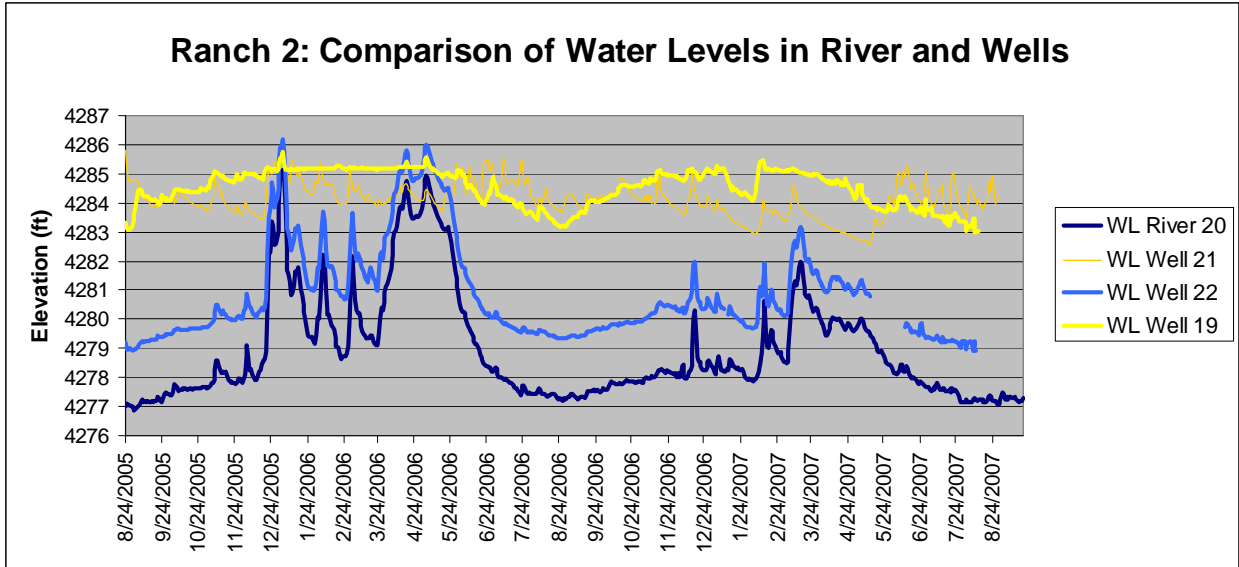


Figure 28. Ranch 2 Comparison of Water Levels in River and Wells.

An important factor to understand in this study is how quickly excess irrigation water moving from one point to another affects the shallow ground water levels with contributions both from overland flow and subsurface drainage. Sites 14 and 15 are part of the same irrigated field. Irrigation water is generally applied near site 14 and allowed to flood the field for 7 to 10 days. The observed rise in the water table level at site 15 lags behind that of site 14 by four to nine days. The distance between these two sites is 1,360 feet.

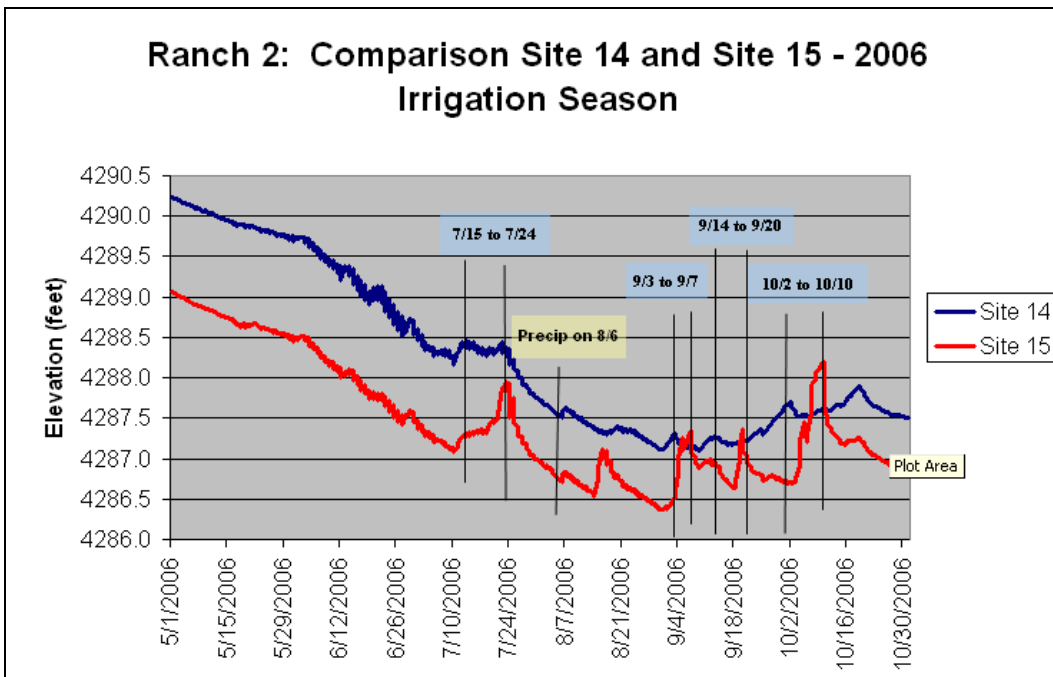


Figure 29. Ranch 2 Comparison of Sites 14 and 15.



This lag that occurs under irrigation is not evident during rain events. Note on August 6, 2006, this area received approximately 0.7 inches of rain. Both wells responded simultaneously with a 0.1 foot rise in water levels on the following day. The evaluation of water movement from site 14 to site 15 indicates that excess irrigation water moves overland and through subsurface at a rate of about 135 to 200 feet per day.

**Table 21: Water Quality Results from Limited Samples on Ranch 2.**

Sample Site	No. of Samples P	Total Phosphorus mg/l	Ratio TP Site to TP Stream	No. of Samples N	Total Nitro-gen mg/l	Ratio TN Site to TN Stream
Stream	2	0.0813	1.00	1	0.4440	1.00
Irrig. Ditch	2	0.0924	1.14	1	0.4800	1.08
Shallow Well	2	3.3980	41.82	1	7.7400	17.43
Shallow Well	2	2.1920	26.98	1	3.5300	7.95
Seep	2	0.2770	3.41	1	0.2640	0.59
Surface Tailwater	2	2.1450	26.40	1	8.4700	19.08
Wetland Outlet	2	0.3800	4.67	1	1.5700	2.74

Water quality samples were taken from shallow ground water, seeps, surface tail water and a wetland outlet to compare nutrient levels in both to the river and the water being diverted for irrigation. The results, while not meaningful statistically due to the limited number of samples, showed that concentrations of both total phosphorus and total nitrogen (nitrate/nitrite) in shallow ground water and surface tail water were higher in nutrients than the river. Results taken from riverbank seeps were less dramatically different from the river. A portion of the surface tailwater return to the river first flows through a wetland adjacent to the stream. Samples taken at wetland's outlet showed both a reduction in phosphorus and nitrogen compared to surface tailwater.

### 3.2.6 Simulation of Irrigated Management Scenarios for Ranch 2

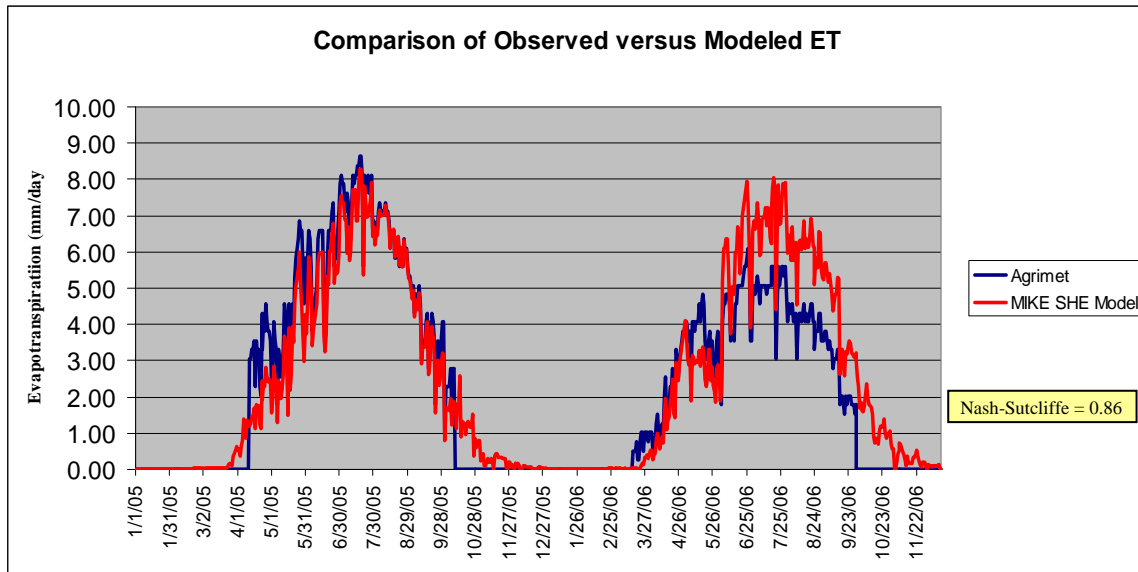
Five management scenarios, including "No Irrigation," were evaluated and compared on this ranch, as listed in the table below.

**Table 22: Ranch 2 Management Scenarios.**

Scenario	Irrigation System	Diversion Rate (gpm)	Level of Forage Management
1	No Irrigation	None	No Grazing
2	Wild flood	2,000	Fair
3	Wild flood	2,000	High
4	Gated Pipe	1,200	High
5	Sprinkler (Wheel lines)	1,200	High

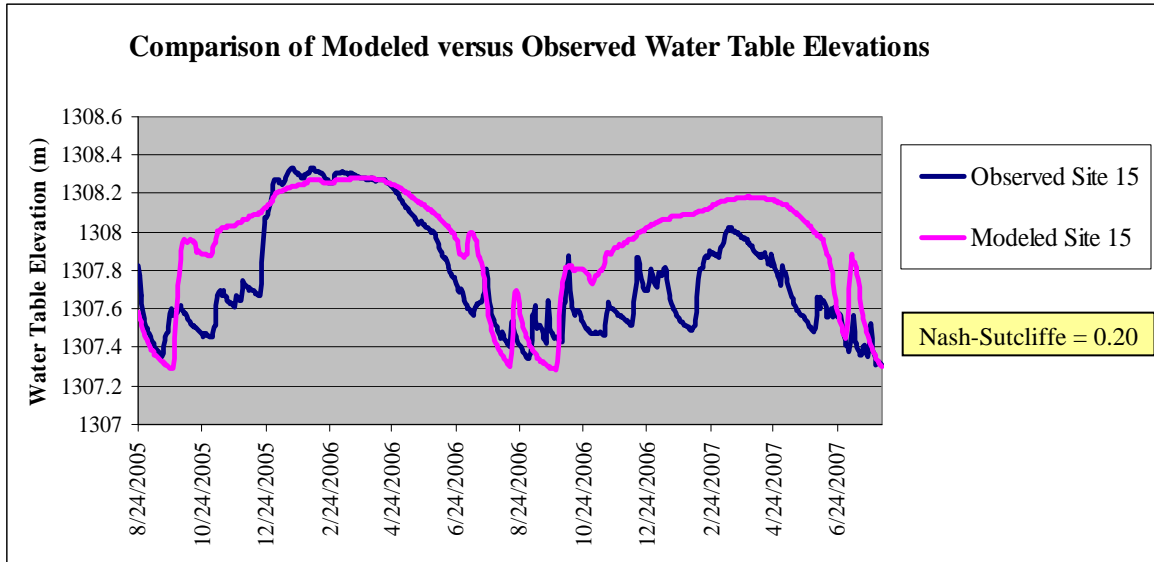
The validity of the model calibrated using the previous, non-irrigated ranch 1 data was tested on this ranch. First, evapotranspiration for scenario 5 (considered optimally

irrigated) was compared to the potential ET measured at the AgriMet Station near Beatty. The model performed well, achieving a Nash-Sutcliffe statistic of 0.86.



**Figure 30. Comparison of Observed versus Modeled Evapotranspiration.**

The second test was to compare observed water table elevations with those modeled. Scenario 2 was assumed to most closely represent current irrigation and grazing conditions on this ranch. Comparing water levels observed and simulated at site 15 resulted in a Nash-Sutcliffe of 0.2. Actual irrigation levels were not collected for this study. Model simulations were instead based on the landowner's post-irrigation memory of the schedule (application areas and timing) and amounts applied. Also during the second year of study, one of the fields was converted from wild flood to gated pipe irrigation. These two factors contributed to a less than ideal statistic fit. However, when the Nash-Sutcliffe was calculated for only the time period before the conversion to gated pipe (August 24, 2005, to August 16, 2006), it produced a higher statistic of 0.58, indicating a much better fit of observed data compared to simulated results.



**Figure 31. Comparison of Observed versus Modeled Water Table Elevations.**

The period simulated with the MIKE SHE model was from January 1, 2004, until September 30, 2007, which covers three complete water years and four irrigation seasons. The water year, as defined for this report, starts on October 1<sup>st</sup> and ends the following year on September 30<sup>th</sup>. The irrigation season was defined as the time period between April 15<sup>th</sup> and October 15<sup>th</sup>.

<b>Table 23: Ranch 2 Simulation Results – Part A.</b>								
<b>Scenario</b>	<b>Average Annual Values (Water years 10/2004 thru 9/2007)</b>							
	<b>Precip (mm)</b>	<b>Irrigation (mm)</b>	<b>Total Water (mm)</b>	<b>Total ET (mm)</b>	<b>Total Transpiration (mm)</b>	<b>Total Evap (mm)</b>	<b>ET/ Total Water (%)</b>	<b>Trans/ Total Water (%)</b>
1. No Irrigation or grazing	355	0	355	414	268	146	117%	75%
2. Wild flood, 2000 gpm, fair forage management	355	1,050	1,405	566	230	336	40%	16%
3. Wild flood, 2000 gpm, high forage management	355	1,050	1,405	670	346	324	48%	25%
4. Gated Pipe, 1200 gpm, high forage management	355	640	995	718	411	307	72%	41%
5. Sprinkler, 1200 gpm, high forage management	355	626	981	900	549	351	92%	56%

The simulations revealed several significant observations:

- The total evapotranspiration (ET) increased with improvements to the irrigation systems. Sprinkler irrigation (scenario 5) increased ET by 59 percent over wild flood (scenario 2).

- Plant transpiration also increased with irrigation improvements. Sprinklers increased plant transpiration by 139 percent over wild flood.
- Irrigation efficiency, measured as the percentage of water evapotranspired out of the total water applied (precipitation plus irrigation), increased with irrigation improvements.
- Efficiency, measured as the amount of plant transpiration versus total water applied, also increased significantly with irrigation improvements.
- Scenarios 2 and 3 compare forage management effects on the water budget. They demonstrate that well-managed forage transpired more water and lost less to evaporation. Highly managed pasture transpired 50 percent more water than low-managed, which should also translate into more forage production.

The following table summarizes similar information, but only for the irrigation season months of the year. It also includes estimates on the destination of excess irrigation water (above plant needs). This includes the amounts lost to overland and subsurface outflow. “Total Other” represents the recharge or deep percolation to ground water and the net change for water stored in the unsaturated soils.

<b>Table 24: Ranch 2 Simulation Results – Part B.</b>							
<b>Scenario</b>	<b>Average Annual Irrigation season Values (April 15 to Oct. 15 for the Years 2004 - 2007)</b>						
	<b>Total Water Available (mm)</b>	<b>Total ET (mm)</b>	<b>Total Transpiration (mm)</b>	<b>Total Evaporation (mm)</b>	<b>Total Overland Outflow</b>	<b>Total Sub-surface Outflow</b>	<b>Total Other</b>
2. Wild flood, 2000 gpm, fair forage management	1,085	496	216	279	393	31	165
3. Wild flood, 2000 gpm, high forage management	1,085	589	321	268	391	30	74
4. Gated Pipe, 1200 gpm, high forage management	694	630	376	254	61	38	0
5. Sprinkler, 1200 gpm, high forage management	667	822	513	308	7	22	0

The data above are also demonstrated in the charts below. They identify the portions of the hydrologic budget going to evaporation, transpiration, overland outflow, subsurface outflow, and other losses that occur during the irrigation season. They plainly demonstrate a more efficient use of water as irrigation water management improves, going from wild flood to gated pipe to sprinklers. Irrigation improvements increased plant transpiration and reduced water lost to runoff, drainage, and seepage. Evaporative losses actually increased with sprinkler use due to the frequent wetting of foliage and soil surfaces.

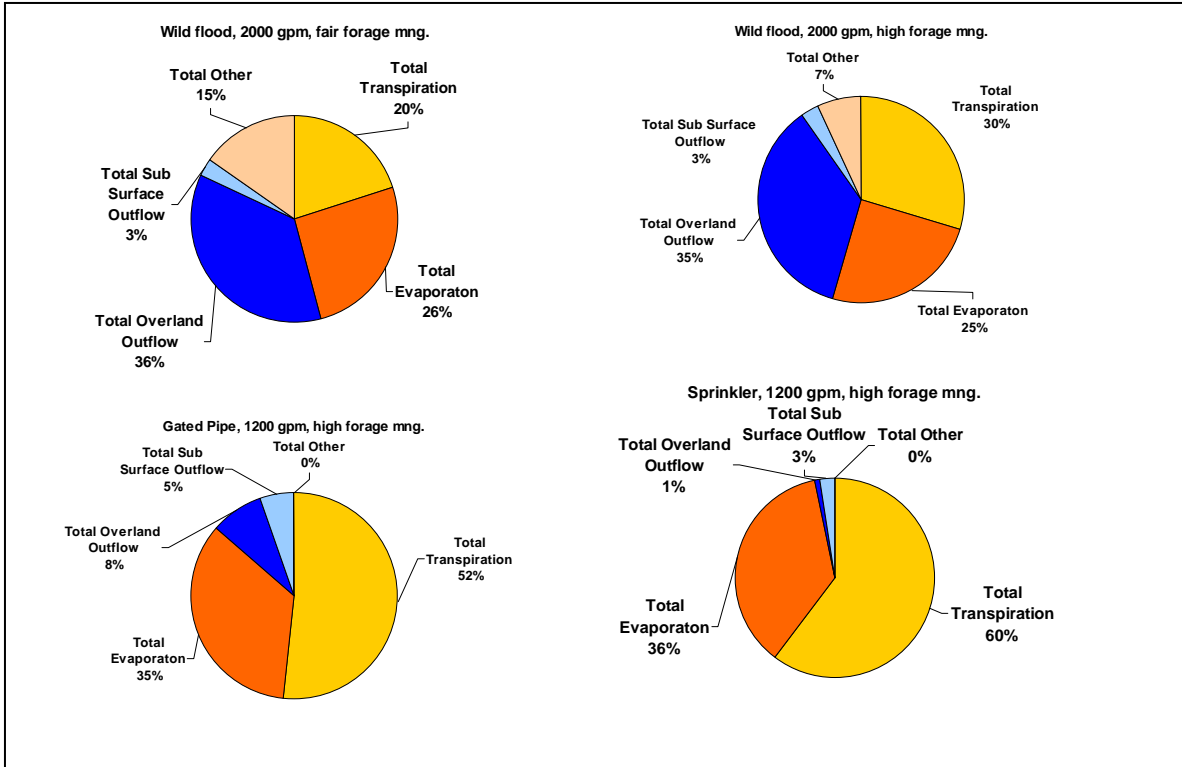


Figure 32. Pie Charts Comparison of Irrigation Scenarios.

Scenario	Irrigation Water Diverted from River (mm/acre)	Total Outflow Returned to River (mm/acre)	Net Water Loss from River (mm/acre)
Wild flood, 2000 gpm, fair forage management	999	424	575
Wild flood, 2000 gpm, high forage management	999	421	578
Gated Pipe, 1200 gpm, high forage management	609	99	511
Sprinkler, 1200 gpm, high forage management	583	29	553

The adjacent table quantifies the net loss to river flow due to irrigation during the irrigation season. The wild flood irrigation scenarios resulted in the greatest losses; however, the net water losses between scenarios are not vastly

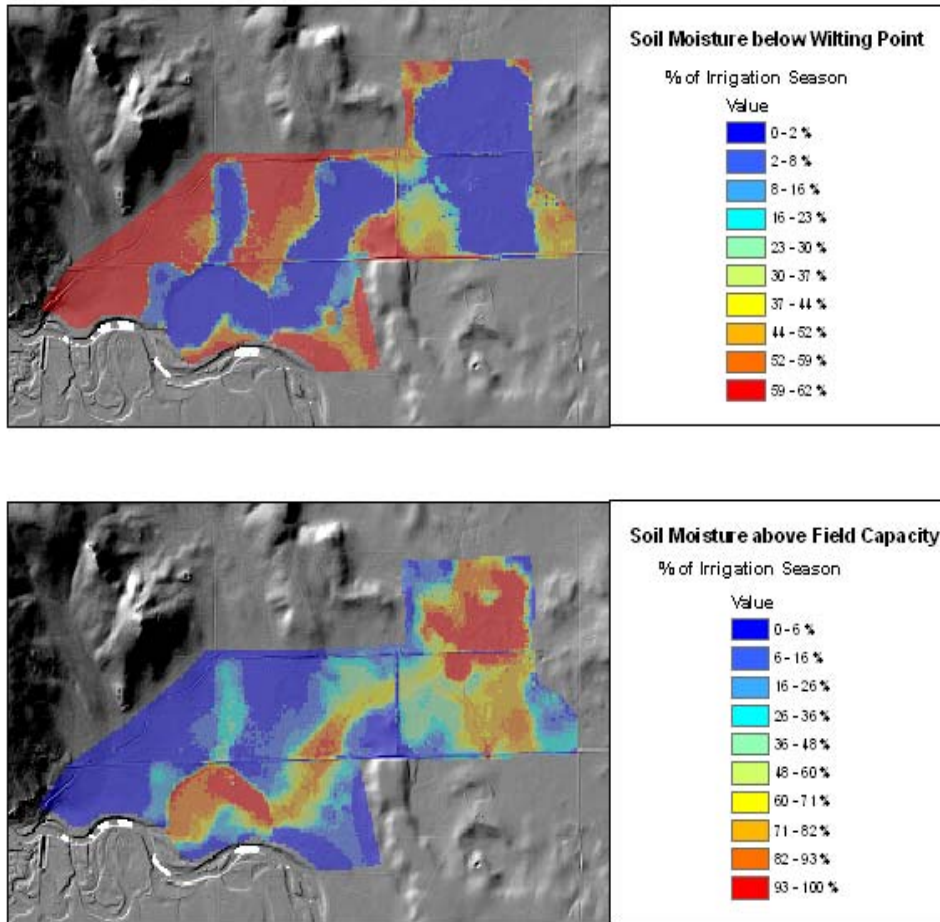
different. This equates to an average loss in stream flow during the irrigation season of 1.7 to 1.9 cfs from this 360-acre irrigated ranch.

The uniformity of irrigation water application increased significantly when going from wild flood to gated pipe to sprinklers. The following table lists the percent area of the 360-acre ranch whose soil moisture content during the irrigation season lies between the wilting point and field capacity criteria.

<b>Table 26: Soil Moisture Content During Irrigation season (April – Oct.).</b>			
<b>Scenario</b>	<b>Percent &gt; WP Criteria</b>	<b>Percent &lt; FC Criteria</b>	<b>Percent Between WP &amp; FC Criteria</b>
<b>1. No Irrigation</b>	0%	100%	0%
<b>2. Wild flood, 2000 gpm, fair forage management</b>	51%	78%	29%
<b>3. Wild flood, 2000 gpm, high forage management</b>	47%	85%	29%
<b>4. Gated Pipe, 1200 gpm, high forage management</b>	50%	92%	42%
<b>5. Sprinkler, 1200 gpm, high forage management</b>	80%	95%	75%

The following figures display the soil moisture distribution for scenarios 2, 4 and 5. The figures show soil moisture conditions based on the percentage of the irrigation season, from April 1 until October 20, which exceeded either the wilting point or the field capacity criteria.

**Wild flood, 2000 gpm, Fair Forage Management**



**Figure 33. Maps of Soil Moisture Distribution for Wild Flood at 2,000 Gallons Per Minute.**

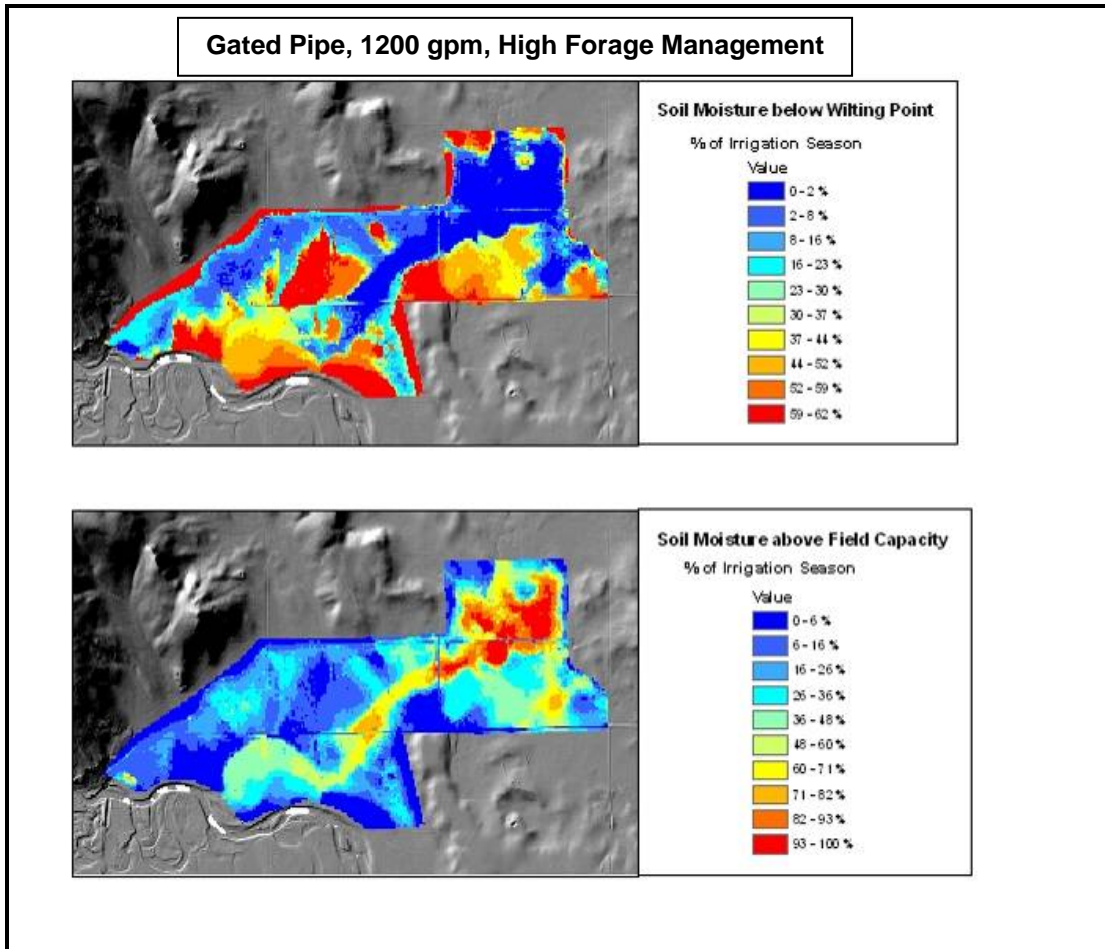
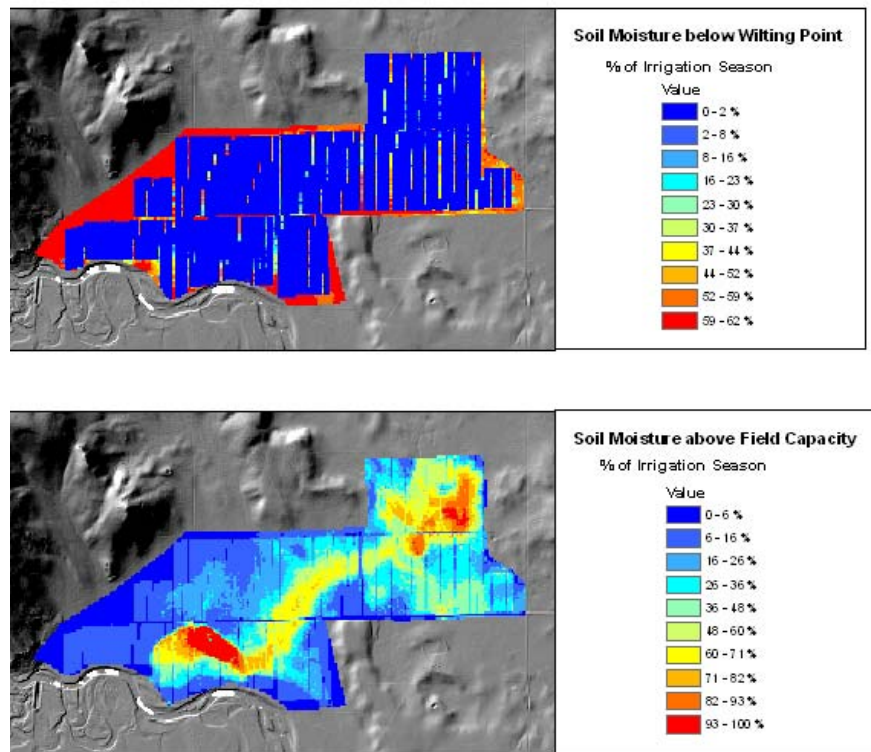


Figure 34. Maps of Soil Moisture Distribution for Gated Pipe at 1,200 Gallons Per Minute.



**Sprinklers, 1200 gpm, High Forage Management**



**Figure 35. Maps of Soil Moisture Distribution for Sprinklers at 1,200 Gallons Per Minute.**

The areas of blue and deeper blue colors seen in these figures indicate that higher percentages of the fields were able to maintain an ideal soil moisture range between wilting point and field capacity. Conversely, the red and yellow sections indicate areas with not enough water (below wilting point), or areas with too much water (above field capacity). Pasture grasses will go dormant in dry soils or die out if soils remain ponded or saturated for long periods of time. Therefore the cells that are blue in both the “above field capacity” and “below wilting point” analyses have sustained optimal moisture content throughout the irrigation season.

Another important comparison between alternative irrigation systems is the amount of excess water applied to the field that is lost via overland or subsurface outflow, as well as the timeframe in which this occurs. Maintaining stream base flow during the late summer and early fall is critical for instream fisheries. Similarly, downstream flow to the Upper Klamath Lake during the irrigation season is important for the lake and downstream users, including other irrigators and fisheries in the Lower Klamath River. The following table estimates the percentage of excess water applied through precipitation or irrigation that returned to the river during the irrigation season.

<b>Scenario</b>	<b>Average Values During Irrigation season (April 15 to Oct. 15 for the Years 2004 through 2005)</b>					
	<b>Total Water Applied as Precipitation or through Irrigation (mm)</b>	<b>Total Inflow from Off the Property (mm)</b>	<b>Total Evapotranspiration (mm)</b>	<b>Excess Water above ET (mm)</b>	<b>Total Overland and Subsurface flow off Property (mm)</b>	<b>Percent of Excess Water Returned to River (mm)</b>
1. No Irrigation or grazing	340	283	351	272	21	8%
2. Wild flood, 2000 gpm, fair forage management	1,085	170	496	759	424	56%
3. Wild flood, 2000 gpm, high forage management	1,085	196	589	691	421	61%
4. Gated Pipe, 1200 gpm, high forage management	694	156	630	220	99	45%
5. Sprinkler, 1200 gpm, high forage management	667	164	822	10	29	100%

The table shows that wild flood irrigation produced both the greatest amounts of excess water above evapotranspiration and the most total return flow (overland and subsurface outflow) to the river. A high percentage (56 to 61 percent) of excess water applied through wild flood irrigation was returned to the river during the irrigation season. The relatively rapid return of excess flows re-augmented stream flow but may have transported additional nutrients to the river as well.

The table below quantifies average annual and average irrigation season results from the simulated outflows from this property back to the river. Wild flood irrigation scenarios produced significantly more outflow due to the excess water applied via irrigation. The table also shows that subsurface outflow for wild flood irrigation was less than 10 percent of the total outflow. Most loss was from overland flow.

Scenario	Average Annual			Average Irrigation season		
	Over land out-flow (mm)	Sub-surface outflow (mm)	Total out-flow (mm)	Over land out-flow (mm)	Sub-surface outflow (mm)	Total out-flow (mm)
1. No Irrigation or grazing	37	31	68	5	16	21
2. Wild flood, 2000 gpm, fair forage management	797	78	875	393	31	424
3. Wild flood, 2000 gpm, high forage management	723	76	800	391	30	421
4. Gated Pipe, 1200 gpm, high forage management	275	97	372	61	38	99
5. Sprinkler, 1200 gpm, high forage management	44	68	111	7	22	29

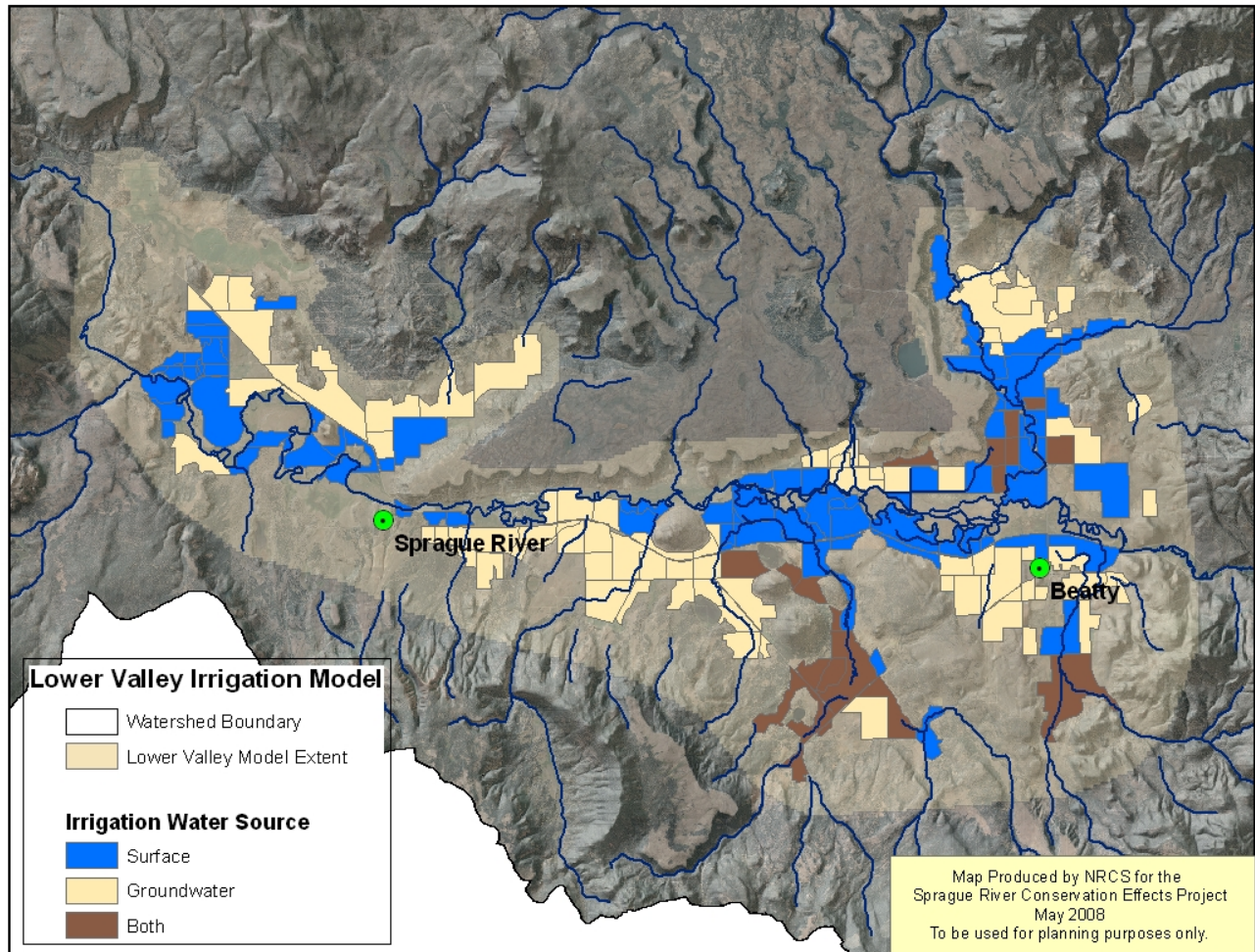
Return flows, whether surface or subsurface, impact water quality by picking up nutrients or other contaminants and delivering them into the river. In addition, shallow surface tail water exposed to direct, radiant heat from the sun probably contributes warmer water to the river as well. Conversely, shallow ground water seeping back to the river should cool excess water to ground temperatures.

Based on the hydrology and available water quality data, the following general conclusions can be assumed about water quality impacts:

- Nutrient loading – for these limited water quality samples, nutrients in overland flow and subsurface drainage are higher in concentrations of TP and TN than in the river itself. Consequently, wild flood irrigation is more likely than gated pipe or sprinkler irrigation to contribute to nutrient loads in the river.
- Stream temperature – since most return flow (90 percent or more) is from shallow, overland flow, it contributes warmer water to the river. Wild flood irrigation, with the greatest volume of return flows, probably impacts stream temperatures more than other, more efficient means of irrigation.

### **3.3 Irrigated Lower Valley Scale Model**

The integrated, distributed hydrologic model, MIKE SHE was dynamically linked to the river hydraulic model MIKE-11, to simulate water movement and stream flow at the lower valley scale. Specifically, the addition of the irrigation module, which allows the user to control the irrigation source, quantity, type, and timing of delivery in the simulation, aided in the determination of how the source of water and the level of irrigation water management affects the stream’s hydrograph and overall water yield.



**Figure 36. Map of the Lower Valley Irrigation Model.**

As defined for this study, the Lower Valley stretches from the Beatty Gap downriver to the head of the S' Ochois Canyon, a distance of about 25 miles. The Lower Valley contains over 26,000 irrigated acres. Based on water rights information from the OWRD<sup>15</sup>, 40 percent of the irrigation water is derived from surface rights (the Sprague River), 48 percent from ground water rights, and 12 percent from both surface and ground water rights. Where irrigated lands have both surface and ground water rights, the ground water right is usually supplemental to the surface right for instances in which the first becomes insufficient for irrigation requirements in a given year.

Based on an inventory conducted during the summer of 2005, NRCS identified and mapped the basic types of irrigation used in the lower irrigated valley of the Sprague River Watershed. This survey found that 51 percent of the fields were irrigated by wild flood, 12 percent by controlled flood, and 37 percent by sprinkler.

Irrigation Type <sup>23</sup>	Source of Irrigation Water <sup>24</sup>			Grand Total	Percent by Type
	Surface	Ground Water	Both		
Wild Flood	8,101	2,602	2,474	13,176	50.6%
Controlled Flood	314	2,748	199	3,260	12.5%
Sprinkler	2,054	7,157	401	9,612	36.9%
<b>Grand Total</b>	10,469	12,506	3,074	26,049	100.0%
<b>Percent by Source</b>	40.2%	48.0%	11.8%	100.0%	

Most of the land is used as irrigated pasture, with some fields also cut for hay. Minor acreage of irrigated alfalfa and grain is grown some years. Livestock is the main economic enterprise of the Lower Valley.

This study's simulation of the Lower Valley's water uses examined the cumulative impact of the landscape position of irrigation sources and irrigation types on the hydrologic budget.

### *3.3.1 Description of the Lower Valley Irrigation Model*

The MIKE SHE model was set up to simulate irrigation and its effects on the Sprague River in the Lower Valley based on the following assumptions:

1. All irrigated acres are used for pasture.
2. A shallow water table is perched on the lacustrine and fluvial sedimentary beds which underlie most of the valley.
3. No interaction is allowed between surface hydrology and the deeper regional aquifer from which most ground water withdrawals occur.
4. The simulation period ran from January 1, 2004, until September 30, 2007.
5. The irrigation season starts June 1<sup>st</sup> and ends October 20<sup>th</sup>.
6. Under current conditions:
  - a. Twenty-six thousand and forty-nine acres are irrigated with an application of three acre-feet per acre, equaling most landowners' water right;
  - b. Fifty-two percent of the irrigation water is assumed to be from surface rights and 48 percent from ground water rights; and
  - c. Thirty-seven percent is irrigated via sprinklers while 63 percent is irrigated via surface flood irrigation.
7. Surface flood irrigation is simulated by the uniform application of water to areas approximating the location of existing field ditches and pipelines.
8. There are two levels of grazing management in the area, defined as:
  - Fair forage management, which maintains a stubble height of two inches or less throughout the summer, and
  - Good forage management, which maintains a stubble height of three inches or greater.
7. The hydrograph at the Beatty (11497500) and Sycan (11499100) gages were used as the inflow boundary to the Lower Valley model.

8. The inflow hydrograph was further adjusted to include 75 cfs spring flow between the Beatty Gap and S' Ocholois Canyon, based on a USGS ground water study<sup>20</sup>

In MIKE SHE model the entire unsaturated zone has to lay above the top of the first layer of the saturated zone (defined by the calculated water table elevation). Thus, it is not possible to model a perched aquifer within the 3-dimensional saturated zone model if the regional deeper aquifer is also included in the model. For the Lower Valley model it was assumed that the shallow perched water table exerts more control over surface and subsurface returns of excess irrigation water than the deeper, regional aquifer.

Four irrigation scenarios, plus a “no irrigation” control, as defined below, were formulated to examine the effects of irrigation on the stream’s hydrograph:

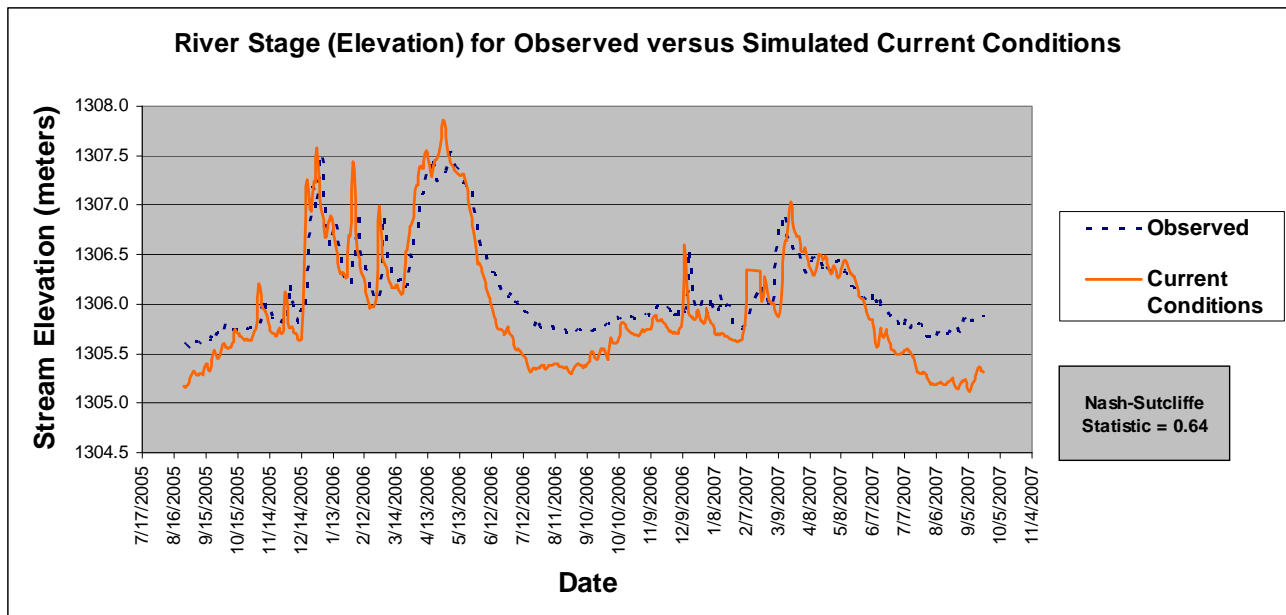
1. No Irrigation – this simulation estimated the hydrograph in lieu of irrigation in order to establish a control that could be compared with irrigation alternatives.
2. Current Irrigation – this simulation was based on the use of 3 acre-foot per acre application with an irrigation type of 37 percent sprinkler and 63 percent surface flood, fair forage management, and a water source that was 52 percent surface water and 48 percent ground water. This simulation most closely approximated conditions in the Lower Valley over the last 10 years.
3. All Ground Water Irrigation – this simulation assumed the use of 3 acre-foot per acre application, an irrigation type of 37 percent sprinkler and 63 percent surface flood, fair forage management, and a water source that was 100 percent ground water. This alternative was formulated to demonstrate the impact that pumping ground water has on the stream’s hydrograph.
4. All Sprinkler Irrigation without IWM<sup>25</sup> – this simulation assumed the use of 3 acre-foot per acre application, fair forage management, and a water source that was 52 percent surface water and 48 percent ground water. This alternative was formulated to demonstrate the impact of applying water via sprinklers without improvements in irrigation water management (IWM).
5. All Sprinkler Irrigation with IWM<sup>26</sup> – this simulation was based on the use of 2 acre-foot per acre application, good grazing management, and a water source that was 52 percent surface water and 48 percent ground water. This alternative was formulated to demonstrate the impact that applying a high level of irrigation water and grazing management might have on the stream.

The following table compares the average amount of evapotranspiration estimated from the water budgets for the ranch scale models within the Lower Valley model. The results seem reasonable given different simulation periods, soils, irrigation methods, water table elevations, and soil moisture conditions. The location of individual fields in the Lower Valley model resulted in variations in water table elevations and soil moisture conditions due to slope, aspect, soils, distance to river, and other tangible factors. The ET values for the Lower Valley Model reflect the average for all 26,000 irrigated acres. ET for the “no irrigation” scenario was less in the lower valley model than estimated for either of the two ranches; however, in the spring, both ranches tend to be sub-irrigated, whereas upland portions of the valley dry out quickly.

Evapotranspiration rates for irrigated lands in the Lower Valley model exceeded the rates estimated for either ranch. The larger cell size used at the valley scale (100-meter versus 10-meter grids) explains much of the difference. Ten-meter grids, used at the ranch scale, reflect real variances in the topography, which impacts surface irrigation application efficiency. Conversely, 100-meter grids averaged elevations over a large area, resulting in the simulation of more evenly sloped fields, which would then be more uniformly irrigated in the model, resulting in a higher overall ET.

Scenario	Evapotranspiration (Ave mm/year)		
	Ranch 1	Ranch 2	Lower Valley
No Irrigation	339	414	320
Current Irrigation	773	566	804
Sprinkler Irrigation with IWM	776	900	936

A valid test of the model’s ability to correctly simulate the irrigated hydrology of the Lower Valley was needed to compare the observed hydrograph with the modeled results that represented the area’s current conditions. NRCS had measured water elevations (stage) at a location near the river’s outflow from the Lower Valley reach for several years. Stream elevations at the same location were outputted from the model for the current condition scenario. A Nash-Sutcliffe statistic of 0.64 was computed for the observed stream elevations compared to the modeled elevations. The model’s accuracy in simulating current irrigated conditions in the Lower Valley provided verification as to its ability to simulate hydrographs for other irrigation management scenarios.



**Figure 37. River Stage (Elevation) for Observed versus Simulated Current Conditions.**

### 3.3.2 Simulation of the Lower Valley Irrigation Management Scenarios

The hydrograph for each irrigation scenario was compared to the simulated no irrigation scenario. The main comparisons were made between stream stage, stream flow, and water yield. The following charts display the stream stage/elevation for each of the irrigation scenarios using the MIKE SHE model over the four-year simulation period (January 1, 2004, through September 30, 2007).

#### Current Conditions versus No Irrigation

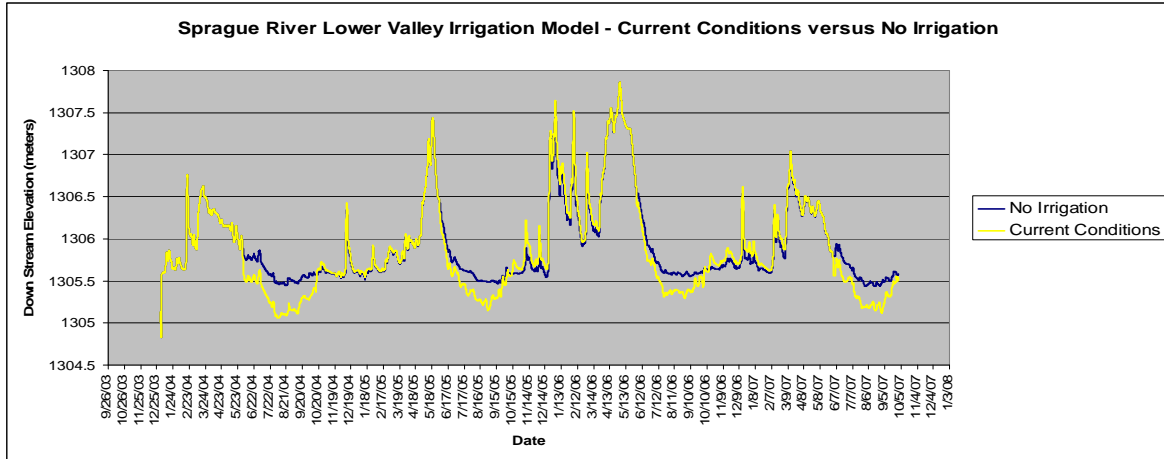


Figure 38. Lower Valley Irrigation Model - Current Conditions versus No Irrigation.

Observations:

- During the summer months, the base flows were lower for the current condition irrigation scenario.
- In the fall and winter, stream flows were actually slightly higher under the current condition irrigation scenario than the no irrigation scenario, with flows for each scenario becoming similar in the late winter to early spring.

#### All Ground Water Irrigated versus No Irrigation

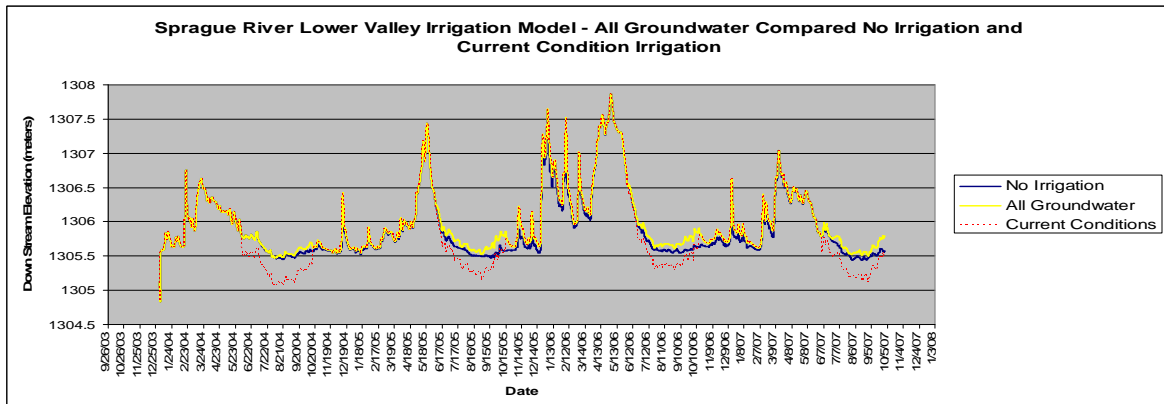


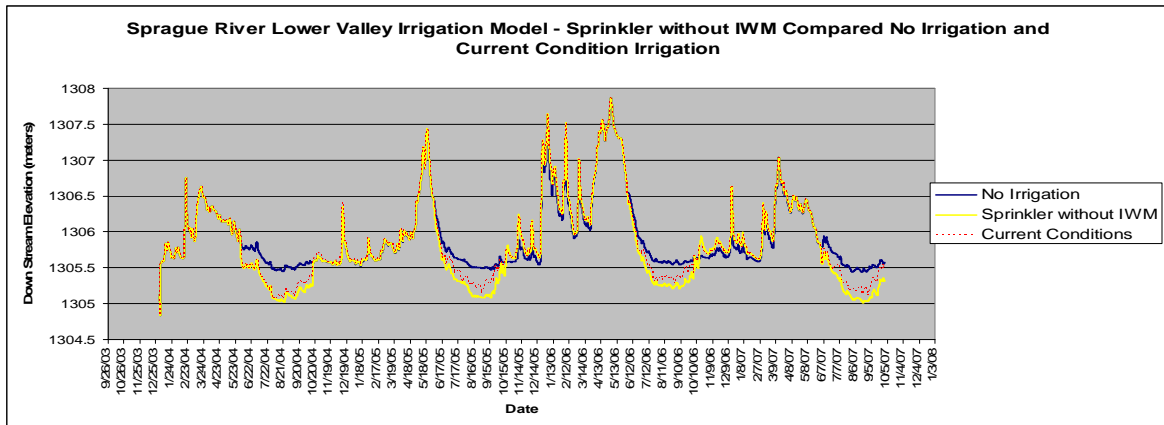
Figure 39. Lower Valley Model - All Groundwater Irrigation Versus No Irrigation.



Observations:

- When 100 percent of the water used for irrigation was supplied from ground water, surface and subsurface return flows supplemented the stream base flow during the irrigation season.
- In the fall and winter, stream flows were also higher under the all ground water irrigation scenario, and they became similar to flows under the no irrigation scenario in late winter or early spring, prior to the start of the following year's irrigation.

**All Sprinkler Irrigation without IWM versus No Irrigation**

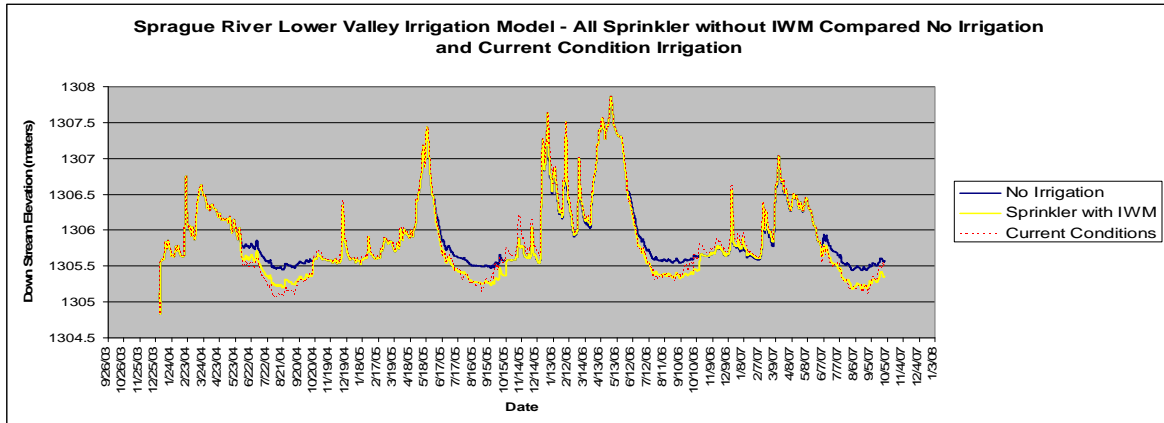


**Figure 40. Lower Valley Model - All Sprinkler Without IWM Versus No Irrigation.**

Observations:

- During the summer months, stream base flows were significantly lower with sprinkler irrigation without irrigation water management than with no irrigation.
- Sprinkler irrigation without irrigation water management also produced lower summer base flows than the current condition irrigation.
- There was no detectable gain in stream flow over the fall and winter months with this sprinkler irrigation scenario, presumably due to insignificant return flows to the river.

**All Sprinkler Irrigation with IWM versus No Irrigation**



**Figure 41. Lower Valley Model - All Sprinkler With IWM Compared to No Irrigation.**

**Observations:**

- During the summer months, base flows were lower with sprinkler irrigation with irrigation water management than no irrigation, even though less water was being diverted from the river for irrigation (2 acre-feet compared to 3 acre-feet per acre) under the no irrigation scenario.
- There was also no appreciable gain in stream base flow over the fall and winter months with the all sprinkler irrigation with irrigation water management scenario.
- Stream base flows for sprinkler irrigation with irrigation water management closely followed those simulated for the current conditions irrigation system, with slightly higher base flows in the summer and lower base flows in the fall and winter.

Another way to compare each irrigation scenario’s effect on the Sprague River is to reduce their hydrographs to the average discharge (cms) and average water yield (cubic meters). Their hydrographs, plotted above, show some differences between scenarios over the course of the year. Average discharge and water yield are shown below for each scenario for a water year, irrigation season, and wet season<sup>27</sup>.

Time Period <sup>27</sup>	No Irrigation	Current Conditions	All Ground Water	Sprinkler w/o IWM	Sprinkler w/ IWM
	(cms)	(cms)	(cms)	(cms)	(cms)
<b>Water Year</b>	16.1	15.8	17.3	15.3	15.2
<b>Irrigation Season</b>	7.4	4.7	8.7	3.7	4.7
<b>Wet Season</b>	21.4	22.4	22.4	22.4	21.7

	<b>No Irrigation</b>	<b>Current Conditions</b>	<b>All Ground Water</b>	<b>Sprinkler w/o IWM</b>	<b>Sprinkler w/I WM</b>
<b>Time Period</b>	<b>(cubic meter)</b>	<b>(cubic meter)</b>	<b>(cubic meter)</b>	<b>(cubic meter)</b>	<b>(cubic meter)</b>
<b>Water Year</b>	508,042,913	497,321,603	546,528,661	483,122,466	480,350,822
<b>Irrigation Season</b>	88,265,765	55,507,725	103,278,693	44,069,437	56,496,751
<b>Wet Season</b>	413,683,294	433,052,236	433,126,443	433,135,788	418,625,583

### **Current Conditions versus No Irrigation**

Irrigation water supplied via ground water more or less compensated for increased evapotranspiration from irrigation. Stream flows were lower during the summer irrigation, but the annual water yields were similar. The wet season yields were actually higher than under the no irrigation system, indicating the return period for excess water lasted through the winter.

### **All Ground Water Irrigated versus No Irrigation**

A scenario using ground water as a sole source of irrigation water, would supplement stream flow and water yields throughout the year, based on our model with only a shallow ground water table. However the USGS ground water study will evaluate the potential impact of ground water withdrawal from the deeper regional aquifer. It is possible that additional use of the regional aquifer could impact ground water discharge to the Sprague River that was not captured by our model.

### **All Sprinkler Irrigation without IWM versus No Irrigation**

Converting to sprinklers and applying the full water right of three acre-feet of water per acre reduced the simulated total average annual stream flows and water yield slightly while reducing the summer irrigation stream flows and yield significantly. Over the wet season, yields were similar to those under the current conditions. The main reason for the reductions in discharge and yield was greater ET due to a more uniform application of water. This follows the relationship observed at the field scale, although that relationship was less severe.

### **All Sprinkler Irrigation with IWM versus No Irrigation**

Converting to more efficient sprinkler irrigation, along with irrigation management and scheduling (reducing water use to 2 acre-feet), reduced the total water yield the most of any scenario. It resulted in more ET at a higher percentage of the available water (both

precipitation and irrigation). This scenario generated the least surface or subsurface runoff.

<b>Table 33: All Sprinkler Irrigation with IWM versus No Irrigation.</b>					
Average Irrigation Water Use and Water Year Yield	No Irrigation	Current Conditions	All Ground Water	Sprinkler w/o IWM	Sprinkler w/ IWM
	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet
Irrigation Type					
Flood	0	49,310	49,310	0	0
Sprinkler	0	28,837	28,837	78,147	52,098
Total Water Use	0	78,147	78,147	78,147	52,098
Irrigation Water Source					
River	0	40,628	0	40,628	27,085
Ground Water	0	37,518	78,147	37,518	25,012
Total Water Use	0	78,147	78,147	78,147	52,098
Stream Water Year Yield	411,877	403,185	443,078	391,674	389,427
Reduction in Water Yield over No Irrigation	na	-2.1%	7.6%	-4.9%	-5.5%

“Current conditions” reduced the water yield by 2.1 percent over “no irrigation”, even with the input of 37,500 acre feet of groundwater to the valley via irrigation pumping. “All groundwater” source irrigation is predicted to increase the water yield by nearly 7.6 percent. The “Sprinkler without IWM” scenario diverts the same amount of water from the river as the “Current Conditions” scenario, but it results in 4.9 percent less water yield, again presumably due to the increased rate of ET. And the “Sprinkler with IWM” solution has the greatest impact, reducing watershed yield by 5.5 percent over no irrigation.

### 3.4 General Observations about Irrigation

The ranch and Lower Valley scale irrigation simulations complemented each other. The following observations were derived from those simulations, as well as from the evaluation of field monitoring.

1. Converting from a wild flood to sprinkler system with improved irrigation water management resulted in:
  - a. Increased plant transpiration, which translates into increased forage production;
  - b. Reduced surface and subsurface return flows to the river;
  - c. Produced the most return flow (90 percent) being surface versus subsurface;
  - d. Lowered summer stream base flows;
  - e. Lowered annual water yield from the watershed; and
  - f. Decreased nutrient loading to the river, based on less irrigation return flows.
2. Improving forage management resulted in:

- a. Increased transpiration and reduced evaporation, and
  - b. Improved forage production, based on increased transpiration.
3. Pumping ground water for irrigation (assuming no impact on the regional aquifer) supplemented stream flow under the current conditions scenario, yielding a similar annual outflow from the river as with the no irrigation scenario.
  4. Planning irrigation improvements should be evaluated and implemented on a system versus single practice basis.
  5. Excess irrigation water was returned to the river within six to nine months, with outflow from irrigated fields adjacent to the river (within ¼ mile) returning in 7 to 14 days.

Conservation recommendations for improving irrigation are dependent upon the priority issues for the decision makers, be they landowners or resource managers. If landowners wish to produce more forage, then converting to sprinklers or gated pipe irrigation, along with improved forage management, would be the solution. If the objective were to increase summer base flow for river spawning suckers, then remaining with flood irrigation may be the answer. If the limiting factor for rearing suckers or salmonids were dissolved oxygen, then perhaps converting to sprinklers and reducing irrigation return flows high in nutrients would be best.

The solution could be different still, if the goal were to improve the annual water yield in the Sprague River for downstream uses (irrigation, wildlife, and fish). The only solutions for this priority, based on this evaluation, would be either to increase ground water pumping or to convert from irrigated to non-irrigated pasture. The latter, however would only improve water yield if the conversion to non-irrigated pasture occurred on fields with surface versus ground water rights.

The same general conclusions<sup>28</sup> about water quality were reached at both the ranch and Lower Valley scale analyses, as described below:

- Nutrient loading – based on limited water quality samples, nutrients in both overland flow and subsurface drainage were higher in concentrations of TP and TN than the river itself. Surface irrigation resulted in significantly more surface or subsurface return flows, thus likely increasing nutrient loading in the stream more than a sprinkler system.
- Stream temperature – since most return flow (90 percent or more) was from shallow overland flow, it probably contributed warmer water to the river. Therefore, surface irrigation, with the greatest volume of return flows, would probably impact stream temperatures more than sprinkler irrigation.

A model like MIKE SHE can be used to simulate the effects of a multitude of irrigation management alternatives and the relative magnitude of those effects. Ultimately, decisions on the best course of action on a watershed scale must be based on the priority issues and concerns agreed to by resource decision makers. This analysis demonstrates that one set of actions may have positive impacts on one resource issue but negative impacts on another. For the Sprague River Watershed, information on some of the interrelated action results is dependent upon other research that is still on-going. For

example, the USGS's study of the regional aquifer will provide information on the potential impacts of increased or decreased ground water pumping on surface waters. The United States Fish and Wildlife Service's (USFWS) studies on the life cycle of suckers will better define limiting factors and timing for stream flows and water quality.

Based on this study, the MIKE SHE model, when calibrated and validated, appears to be a hydrologic model well suited for determining the effects of changes in land management on the water budget. With the provision of additional, well-defined goals and objectives, a more fine-tuned, focused MIKE SHE model could be used to provide more specific solutions.

### **3.5 Upland Juniper and Forest Model**

Landowners, scientists, and others have noted the presence of overstocked forests and expanding juniper stands in the entire Upper Klamath Basin, including the Sprague River Watershed. Anecdotal information suggests the occurrence of increased spring flow and stream flow following forest fires and efforts to clear hillsides of juniper. Little research exists to confirm this hypothesis for any area with climate, soils, and geology similar to that found in the Upper Klamath Basin. Furthermore, studies to measure hydrologic changes created by forest thinning and juniper clearing can take decades. Oregon State University, Department of Rangeland Resources is currently conducting a paired watershed study<sup>29</sup> on Camp Creek in central Oregon to evaluate the effects of juniper clearing on hydrology as well as other ecological resources. Their study is currently in its twelfth year and is expected to continue for several more years before conclusive results can be reported.

MIKE SHE was thought to be an appropriate model for simulating the effects of forest thinning and juniper clearing as it covers the entire land phase of the hydrologic cycle. One of the biggest challenges in using the model was to identify a location with enough recent data that the model could be calibrated and validated. Elements such as canopy interception, plant transpiration, rooting depth, overland runoff, soil infiltration rates, the hydraulic conductivity of geologic layers, and ground water discharge to surface waters had to be accurately represented in the model. The area that most closely fulfilled these needs and which was selected for study was the South Fork Sprague River Sub-watershed.

*3.5.1 Description of the South Fork Sprague River Sub-watershed*

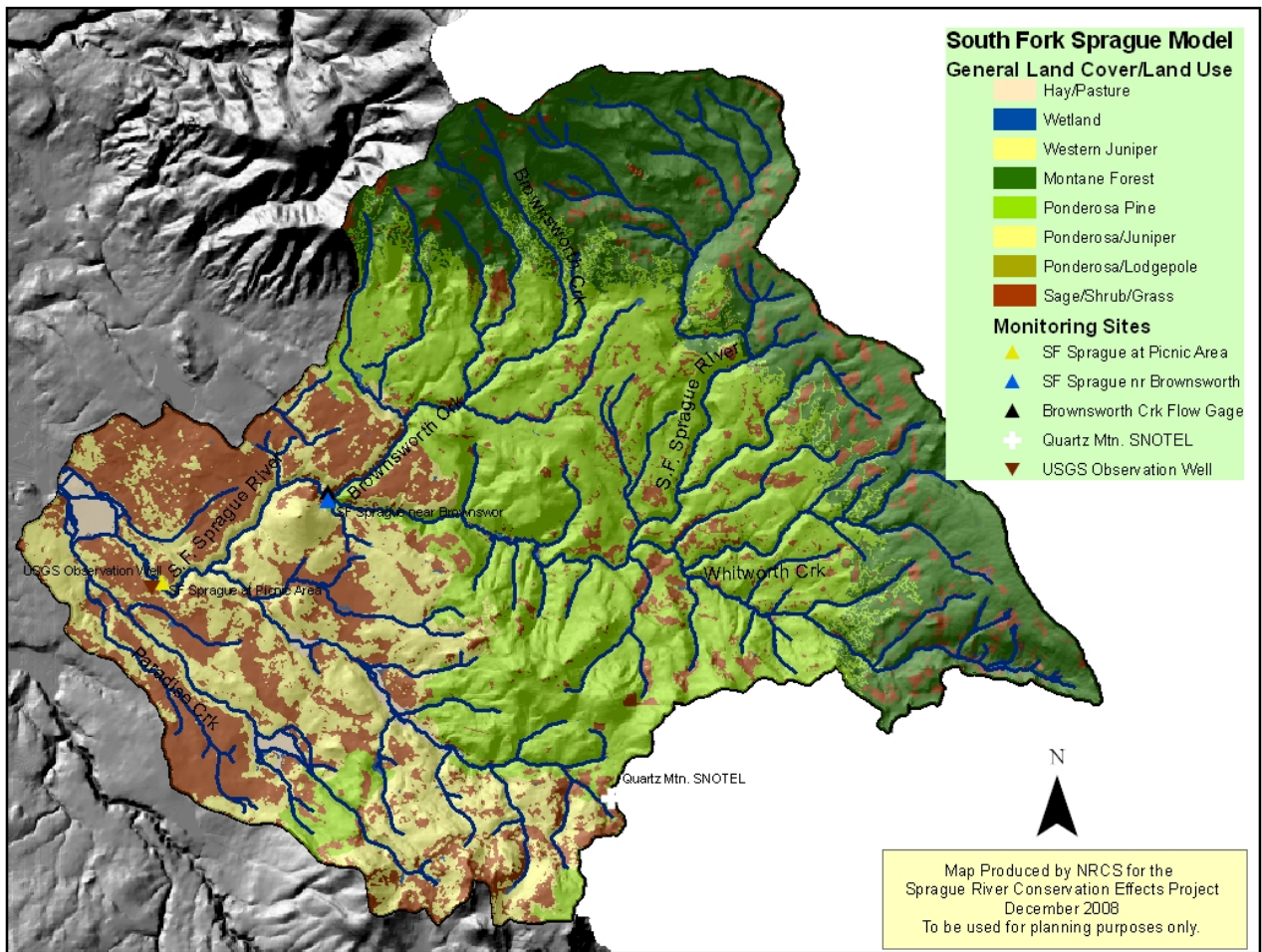
The South Fork Sprague River Sub-watershed covers 82,156 acres. Seventy-eight percent of the watershed is forested. Very little is affected by irrigation, making

**Table 34: South Fork Sprague River Watershed Land Use Land Cover.**

Land Cover/Land Use	Acres	Percent
Irrigated Pasture/Hay	896	1.1%
Wetlands	772	0.9%
Western Juniper	10,840	13.2%
Montane Forest	19,237	23.4%
Ponderosa Pine	30,679	37.3%
Ponderosa/Juniper Mixed	3,294	4.0%
Ponderosa/Lodgepole Mixed	110	0.1%
Sagebrush/Grass/Shrub Land	16,328	19.9%
Total	82,156	100.0%

conditions ideal for simulating the impacts of forest activities. Five historic monitoring sites were found in the watershed that proved useful for model calibration. Three stream flow gages with periodic records were located on the South Fork Sprague River, one at the state park picnic area near the river’s mouth (Forest Service gage SS1), the second on the South Fork River near Brownsworth Creek (SS2), and the third on Brownsworth Creek (BW1).

In addition, NRCS operates a SNOTEL site along the southeastern boundary of the watershed at Quartz Mountain, where snow depth, the snow water equivalent, precipitation, temperature, soil moisture, and other meteorological data are recorded. Information on quarterly water table elevations exist due to a USGS observation well (51001) also located near the state park picnic site. Finally, stream flow data on the South Fork Sprague River near the picnic area has been gathered biweekly since 2001 by the USFS and the Klamath Tribes and daily since 2004 by a consultant for the Tribes. These combined data were thought to be sufficient to calibrate the MIKE SHE model.



**Figure 42. Map of Land Use Land Cover in South Fork Model.**

### *3.5.2 Hydrologic Simulation of the South Fork Sprague River Sub-watershed*

The MIKE SHE hydrologic model was first formulated to represent the current conditions in the South Fork Sprague River in order to calibrate the model and to generate data on hydrologic conditions. Juniper and forest vegetation was broken down into four canopy classes (see Section 2.7.2): canopy less than 25 percent, 26 to 50 percent, 51 to 75 percent, and 76 percent or over. The USGS provided the description and map of geologic layers used to represent the deep, regional aquifer. The same spatially distributed meteorology and soil information was used as was previously described in this report.

Unfortunately, with the amount of time and funds available for this step of the Sprague River CEAP study, researchers were not able to adequately calibrate the model to the observed stream flows or water table levels (see following plots).



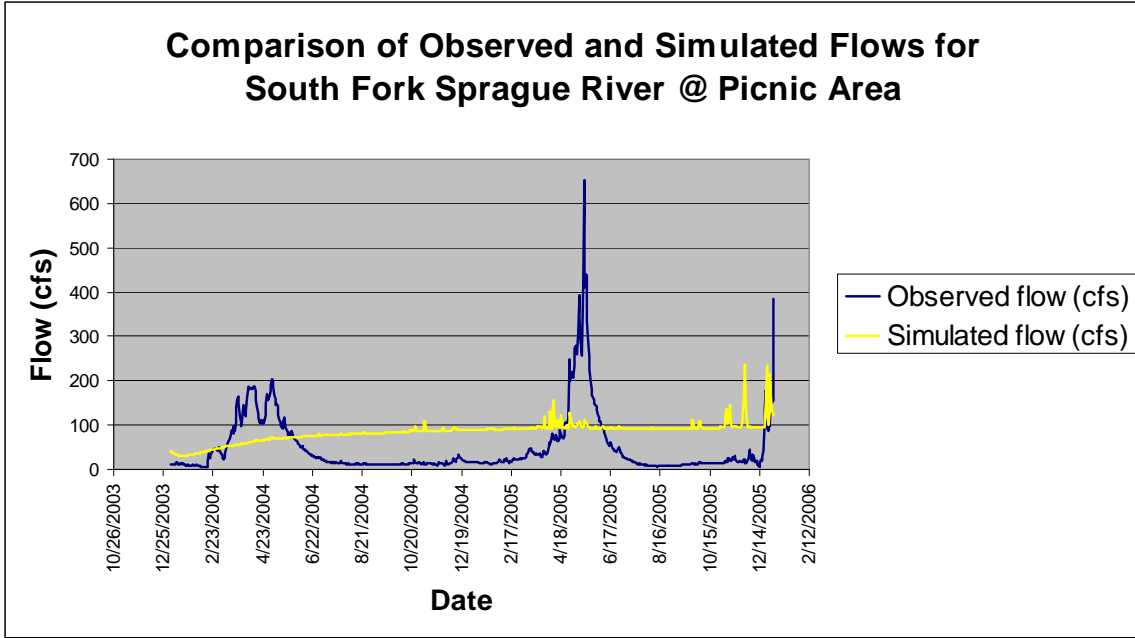


Figure 43. Graph of Observed South Fork Sprague Flows Versus Simulated Flows.

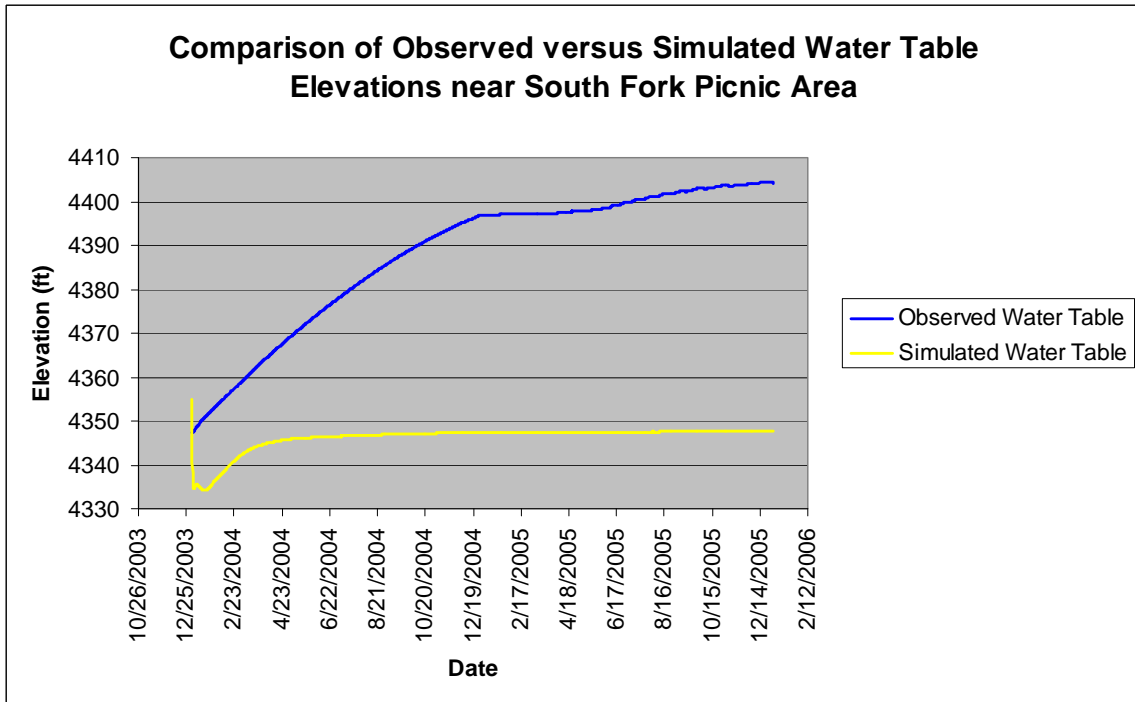


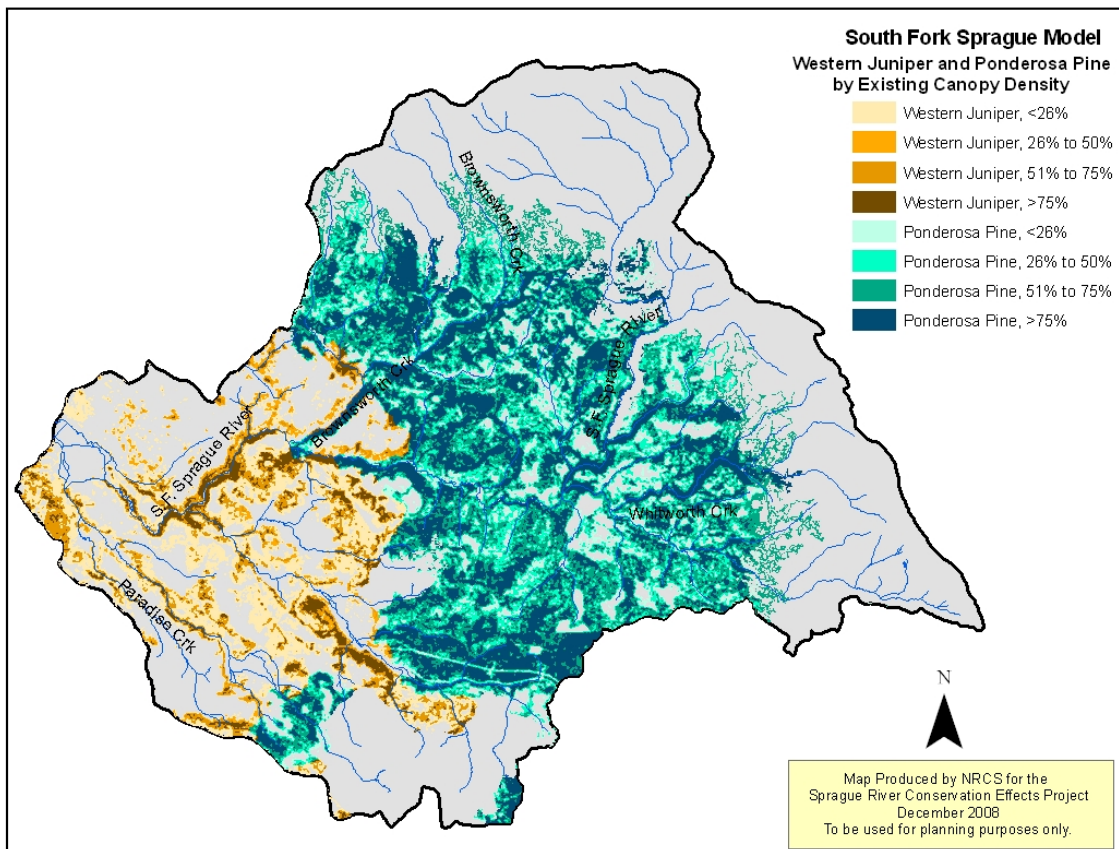
Figure 44. Graph of Observed Versus Simulated South Fork Water Table Elevations at Picnic Area.

Besides time and money, another cause for the calibration difficulties was that the simulations were run for too short of a time to allow the hydraulic head on the water table to equilibrate. Often, ground water models are run to simulate a period of decades in order to allow the water tables and boundary conditions to balance. The MIKE SHE model runs for this study were limited to two year simulations due to limited historic

monitoring data and extremely long computation times for the model (12 or more hours per simulation.)

In addition, CEAP researchers had limited ground water hydrology modeling experience. Originally, they planned to use the USGS's expertise; specifically, the output from their regional ground water study in the Upper Klamath Basin to fill in the ground water boundary conditions for the MIKE SHE model. Unfortunately, the USGS has not yet completed their study.

Finally, at the scale of the South Fork Sprague River Sub-watershed, the interaction between surface and ground water is extremely complex. The generalized description of the geologic layers that was obtained from the USGS may not have been adequate to explain the seasonal stream flow and water table fluctuations actually observed. The USGS, in their studies, is looking at longer term variations.

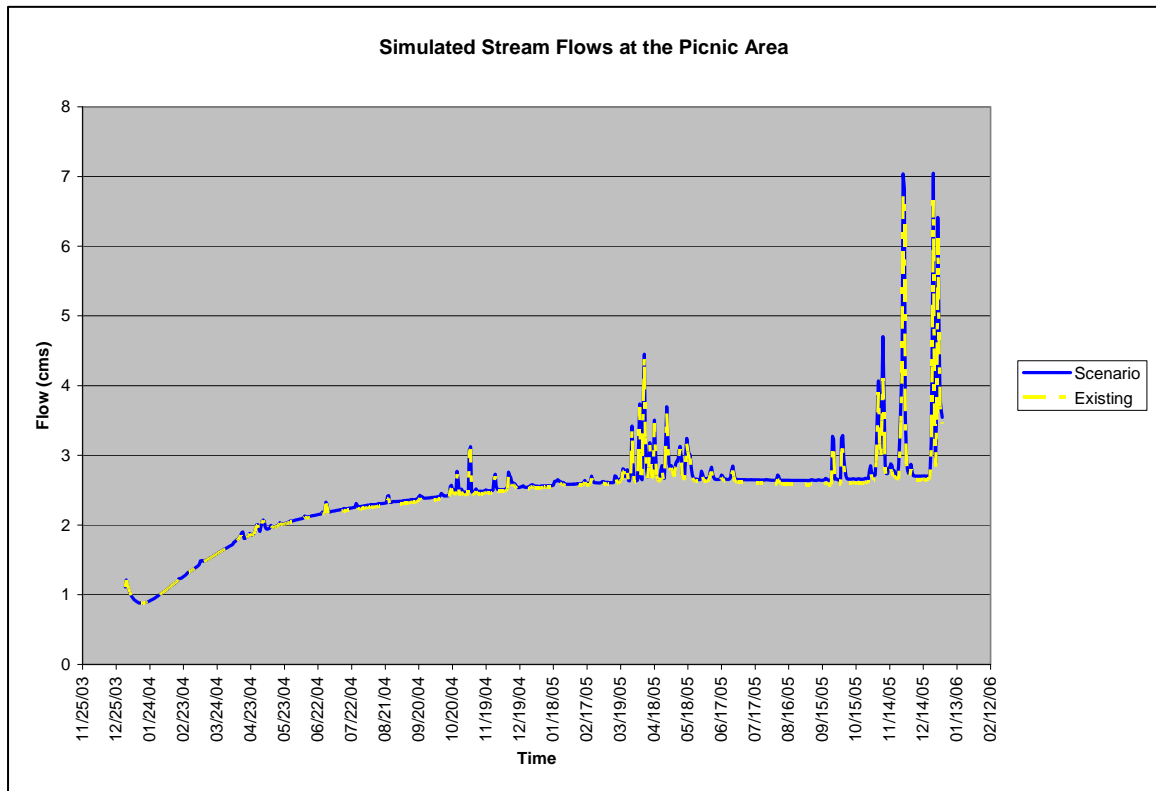


**Figure 45. Map of Western Juniper and Ponderosa Pine Canopy Density for South Fork Sprague.**

Stream flows were simulated for the existing conditions and for one management scenario, even though the model was not calibrated. The management scenario was formulated to represent a maximum possible hydrologic change in which all junipers with canopy densities greater than 25 percent were cleared and all pine stands thinned to 25 percent canopy density or less. This resulted in the simulated treatment of 4,800 acres of

juniper and 27,300 acres of Ponderosa, or 39 percent of the total watershed area. This model assumed that the succession of a sage steppe vegetation type would be established, and function properly in sites removed of juniper.

With this management scenario, based on the un-calibrated model, simulated stream flows increased by 1.5 percent and annual water yield from the watershed by 935 acre-feet.



**Figure 46. Simulated Flows at the Picnic Area.**

The validity of these stream flows from an un-calibrated model is suspect; however, the results for the evapotranspiration and unsaturated zone portions of the water budget may be more credible.

The next plots compare the snow water equivalent and soil moisture levels simulated in the model for the existing conditions versus observations recorded at the Quartz Mountain SNOTEL site. The model adequately simulated the observed values with Nash-Sutcliffe statistics of 0.65 and 0.52, respectively.

Another significant component of the hydrologic budget as it pertains to snow is the portion of snow intercepted in the forest canopy and then lost to evaporation (sublimation). Research by P.M Miller., L.E. Eddleman and others at Oregon State University (see OSU Agricultural Experiment Station Bulletin 152 for additional references<sup>30</sup>) found canopy interception for Western juniper ranges from a high of 42 percent for canopy densities greater than 75 percent to a low of 17 percent for canopies

with a density of less than 25 percent (in Section 2.7.2). Taking a weighted average, by area, of the treated juniper and pine resulted in an estimated overall canopy interception rate of 29 percent. Research by Link, Unsworth, & Marks<sup>31</sup> suggests 30 percent of the snow intercepted in the canopy is lost to sublimation while the other 70 percent eventually melts and drips to the ground. This would suggest 8.9 percent of the precipitation received in this watershed (29 percent interception times 30 percent sublimation) could be lost to forest canopy interception. Based on the MIKE SHE simulation of existing conditions for the treated area, 10.6 percent of the precipitation (mainly snow) was lost.

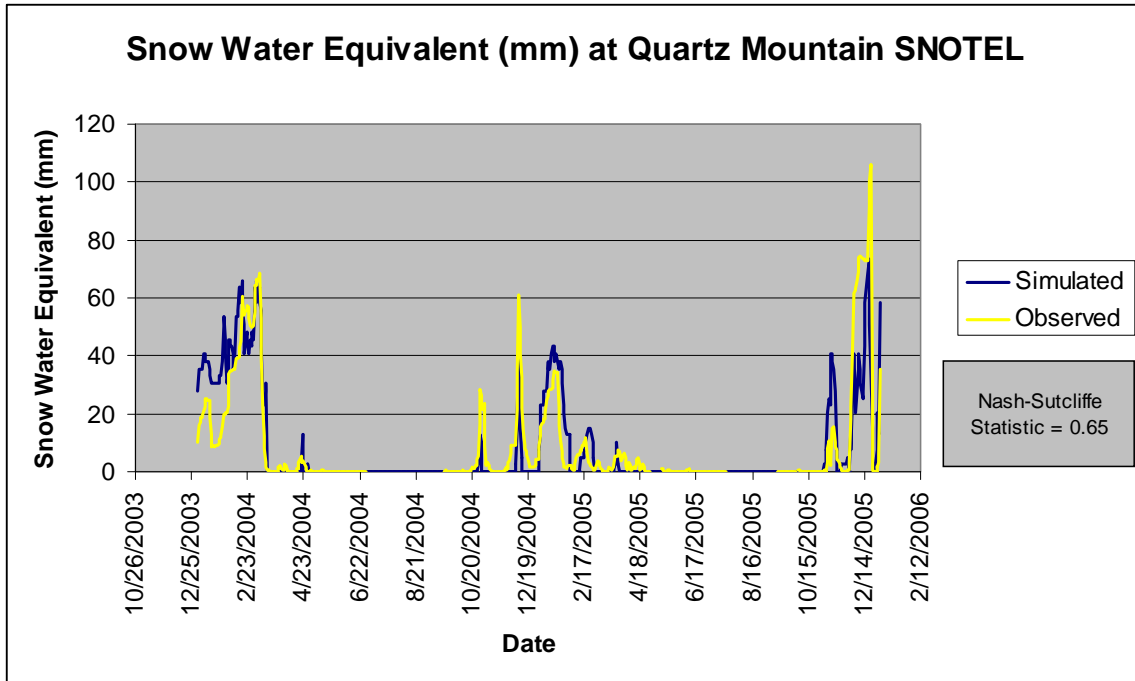


Figure 47. Graph of Observed Versus Simulated Snow Water Equivalents at Quartz Mountain.

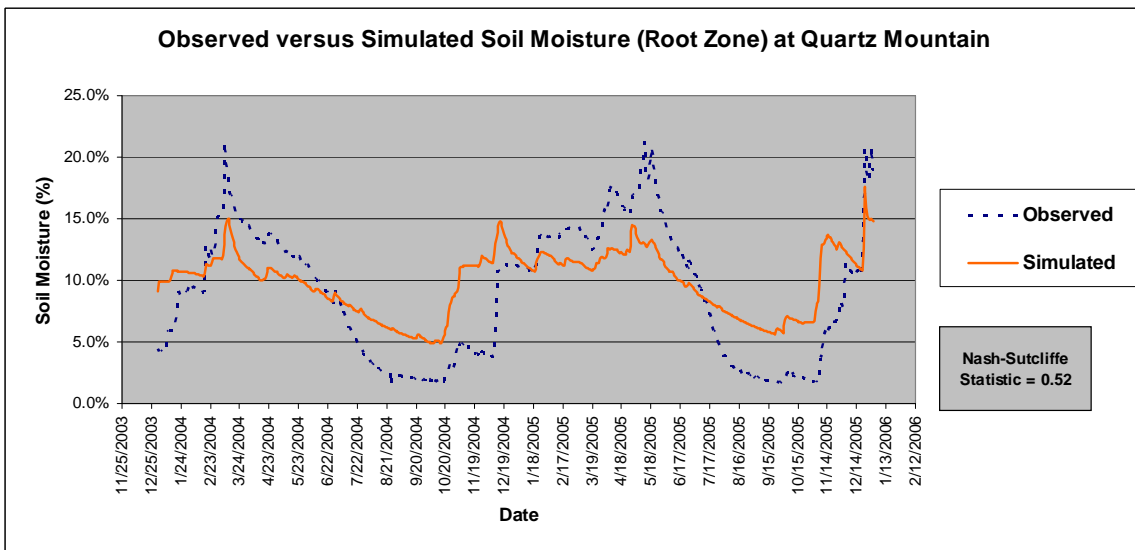


Figure 48. Graph of Observed Versus Simulated Root Zone Soil Moisture at Quartz Mountain.

Soil moisture was compared before and after treatment for a high-density juniper site (greater than 75 percent canopy). Most of the high-density juniper, based on STATSGO soils map, lies on a Merlin soil with a wilting point of approximately 15 percent soil moisture and a field capacity of 30 percent soil moisture for a rooting depth of 60 cm, which is common for most range grasses and forbs. The following chart shows that, under existing conditions, little soil moisture necessary for the survival of grasses and other understory vegetation was available beneath the juniper canopy for most of the year. After treatment, however, there was adequate soil moisture for range plants to flourish.

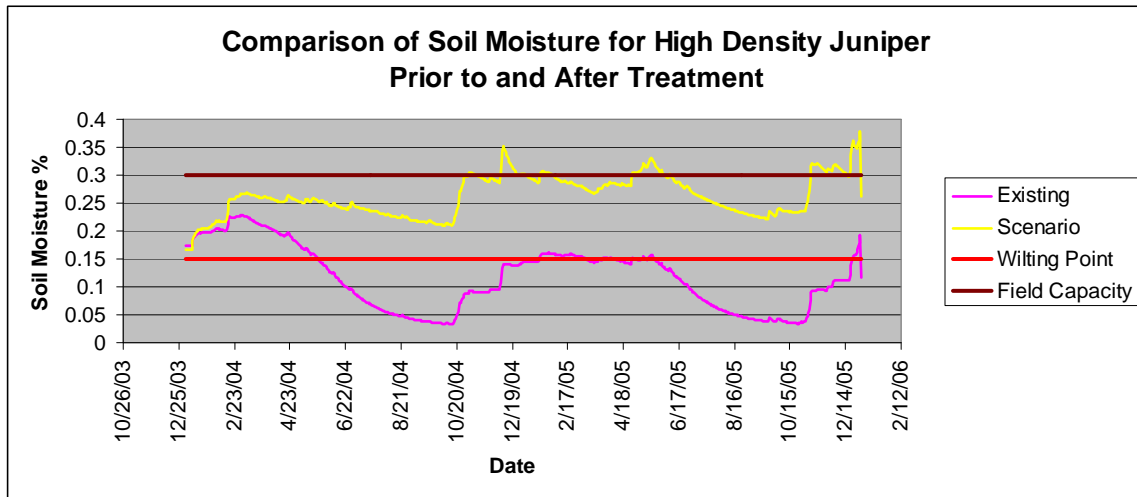


Figure 49. Graph of Simulated Soil Moisture for High Density Juniper Prior to and Post Treatment.

With this in mind, there appears to have been much more significant changes in the simulated water budget than the actual stream hydrograph and ground water table elevations indicated. The following table summarizes the precipitation, evapotranspiration, and transpiration simulated with the model for both the existing conditions and the treated scenario.

Water Budget Item	Existing Conditions	Treated Scenario	Percent Treated of Existing
Precipitation (mm)	572	572	100%
Evapotranspiration (mm)	458	285	62%
Transpiration (mm)	189	94	49%
Evaporation (mm)	269	192	71%
Available Water for Runoff or Infiltration (mm)	114	287	251%

These results indicate that ET can be reduced by over half by clearing juniper and thinning pine, leaving more than twice as much water available for runoff or infiltration into the regional aquifer.

### 3.6 Riparian Restoration Evaluation

The University of Oregon (UO), working under a cooperative agreement with NRCS and the Klamath Tribes, conducted riparian vegetative and ecological processes in the Sprague River Valley as they relate to previous, ongoing, and future restoration efforts. Their study was supplemented by a historical vegetation assessments done by the USGS/UO on river geomorphic processes, which used GIS mapping of the vegetation, floodplain, and channel characteristics from aerial photographs from the 1940s, 1968, and 2000 (funded by the USFWS, report in progress). This section summarizes the information and conclusions from a preliminary report and personal communications with the study researchers<sup>32</sup>.

The purpose of the study (including both 2006 through 2007 data collection and substantial analyses) was to examine vegetation along riparian areas as a response variable on how plant communities vary according to topography and geomorphology, soil type and texture, and soil moisture and land use. The data was used to explore how communities may shift over time in response to release from grazing pressure, how adjacent water management may impact vegetation, and how broad vegetation patterns have changed over time.

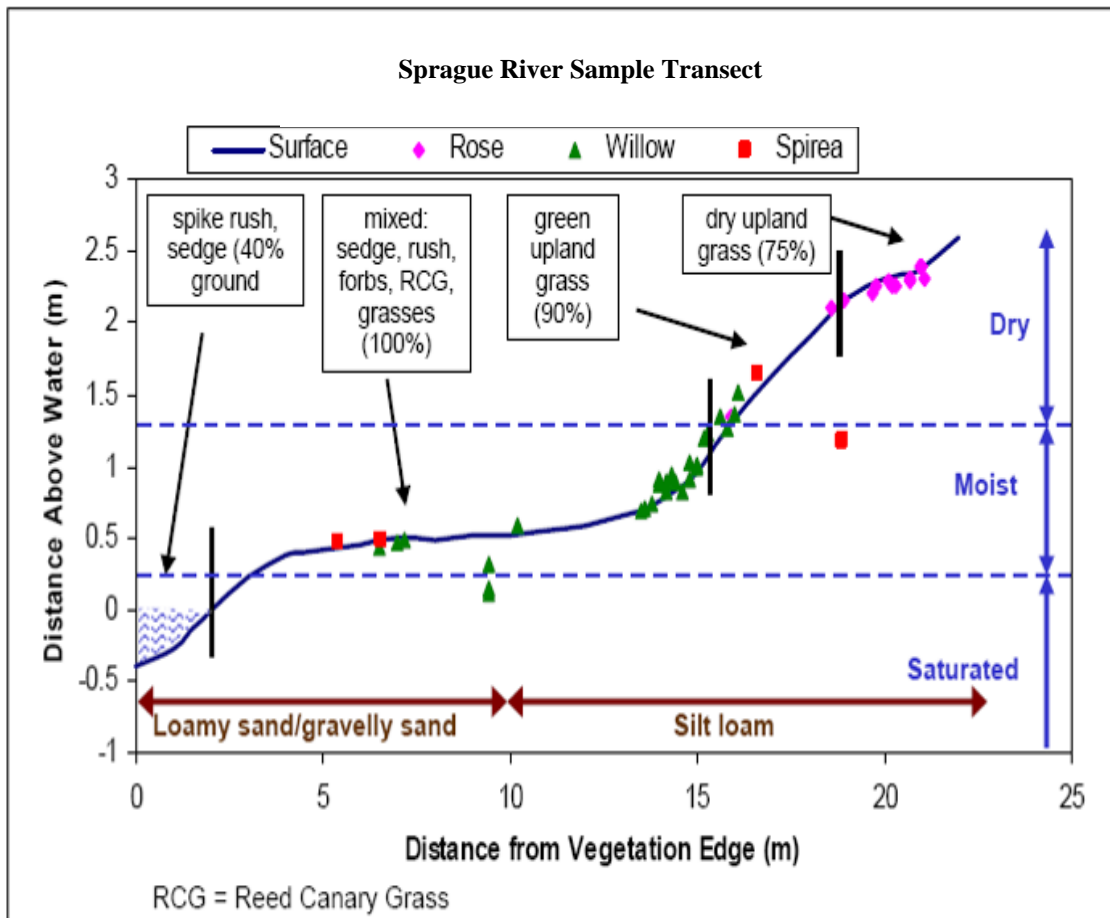


Figure 50. Sprague River Sample Transects.

Thirty-six sites were selected along the valley floor of the Sprague and Sycan rivers. Riparian topography, soil characteristics, general plant communities, riparian widths and heights, and adjacent land management data were collected in this effort. All measurements were based on a linear transects extending perpendicular to the channel from the inner margin of riparian vegetation (typically emergent species) to the dry, upper limit of riparian species.

Some of the University of Oregon's findings include:

- In areas where passive restoration has been put in place and enforced, exposed banks are declining and vegetation rapidly expanding.
- Shrub recruitment on the wide valley reaches seems to be compromised by high water and saturated soils in the spring and summer, at least as much as by drought in the late summer and fall.
- The timing of seed fly and water level drop can compromise shrub regeneration. Willow seeds fly in mid to late June; however June irrigation withdrawals compared to natural conditions lowers the river stage and available stream bank soil moisture levels. In an average year, seedlings can only find adequate water to germinate very low on the bank, putting the new seedlings at high risk of being washed away or drowned during the next high flow season.
- Strong herbaceous cover, especially invasive and aggressive reed canary grass, is likely repressing shrub recruitment.
- In areas undergoing passive restoration, riparian recovery with herbaceous growth is very robust. Even without the regeneration of strong, woody species, the recovery of filtering and bank building processes will be well under way within a couple of years.
- For woody species, restoration efforts have been less rapid. High water, saturation, predation, drought, and competition have compromised natural shrub recruitment for large portions of the Sprague River Valley.
- In most recovering sites, there are many species that are present, vigorous, and actively colonizing soils, but community diversity in herbaceous and woody components seems to be highly site specific.
- In some areas, willow regeneration seems to be supported where subsurface irrigation return flows emerge from high banks.

Several of these findings confirmed the importance of the water regime found in these areas adjacent to the stream. The study emphasized the importance of understanding how land management activities affect water table elevations and soil moisture levels throughout the year. The MIKE SHE hydrologic model has the capability to simulate these effects; however, formulating and calibrating the model for this purpose proved to be beyond the scope of the Sprague River CEAP study.

## 4. Results and Discussion of Conservation Effects

The focus of this CEAP study has been on understanding how conservation practices might affect the watershed's hydrologic budget. Water quantity has been a primary resource concern of landowners and other resource managers in the Klamath Basin since the drought of 2001. Water quality and wildlife habitat concerns are dependent upon the quantity and timing of water availability at certain locations such as in the Sprague River and Upper Klamath Lake, in regional and shallow water tables, in the soil, and in wetland and riparian areas.

Oregon's Water Resources Planning Team selected the MIKE SHE hydrologic model to simulate the effects of conservation practices on the water budget. Confidence in results from simulations increases as the model is calibrated to refine its accuracy and identify deviations and errors. The model was statistically sound when predicting evapotranspiration rates, soil moisture levels, shallow ground water levels, snow accumulation, and stream stage hydrograph (see following table).

<b>Parameter</b>	<b>Model Scales</b>	<b>Nash-Sutcliffe Statistic*</b>
Soil Moisture	Ranch and Sub-watershed	0.52 to 0.82
Shallow Water Table	Ranch	0.38 to 0.92
Evapotranspiration	Ranch	0.86
Snow Accumulation	Sub-watershed	0.65
Stream Elevation (stage)	Reach	0.64

\* The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information"). NSE ranges between negative infinity and 1.0, with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicate that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

Proper calibration was never reached at the sub-watershed scale (South Fork Sprague River) while the model was attempting to simulate the deep, regional aquifer. Consequently, the authors had more confidence in the simulation results of irrigation practices where the model was emulating a shallow ground water table than where the model emulated the affects of juniper control and forest thinning practices in South Fork Sprague River Sub-watershed, which included interactions with the deeper, regional aquifer.

The following sections discuss model results in terms of the questions that have been asked about the effects irrigation practices, juniper control and forest thinning, and wetland/riparian area restoration.

### 4.1 Irrigation System Improvement and Management

A series of questions were posed earlier in the report (Section 1.5 conservation Effects). Summary answers to those questions researchers were able to respond to follow.



(1) How do practices that improve irrigation efficiency affect the timing, amount, and quality of surface and subsurface return flows?

Analyses of field data collected showed excess water applied to a field could move 1,200 to 1,500 feet in seven to fourteen days. Both ranches monitored are adjacent to the river. Most (50 to 100 percent) of the excess irrigation water applied to these ranches is returned to the river during the irrigation season (June 1 to October 20). Based on the simulation of four types of irrigation (wild flood, strip borders, gated pipe, and sprinkler irrigation), irrigation efficiency measured as evapotranspiration as a percent of water applied followed conventional wisdom. This represents a positive impact on crop production, more ET equals more plant growth.

<b>Irrigation System</b>	<b>ET/ Total Water (%)</b>	<b>Trans/ Total Water (%)</b>	<b>Total Evapo-transpiration (mm)</b>	<b>Outflow to River During Irrigation Season (mm)</b>
Wild Flood	40%	16%	566	759
Strip Borders	62%	41%	775	294
Gated Pipe	72%	41%	718	220
Sprinklers	92%	56%	900	10

Conversely, as a greater percentage of the overall water budget is used in evapotranspiration, less outflow (irrigation return flow) returns to the river. This can result in a negative impact to summer a stream base flow which is often a critical time period for fish survival.

Conventional wisdom would suggest improving irrigation systems should have a positive impact on reducing nutrient loading to the river. Irrigation return flows, rich in nutrients, decrease going from wild flood to sprinkler irrigation.

Furthermore, conventional wisdom suggests that improving irrigation systems have a positive impact on stream temperatures. Shallow outflows, associated with flood irrigation, usually gain heat as they flow across irrigated fields, thereby, warming the receiving waters in the stream. The exception would be an irrigation system with strip borders that impede surface returns and encourages *subsurface* flow back to the stream. Subsurface flows would be cooled to nearer ground temperatures depending on subsurface retention time, before seeping back into the river.

The ranch scale analysis elicited potential tradeoffs in conservation effects between stream flow, crop production, and water quality. Decisions regarding the tradeoffs would then depend largely upon the goals and values of landowners, funding agencies and organizations, and society.

(2) What effect do practices that enhance irrigation efficiency have on stream flows?

The Ranch scale simulations demonstrated excess irrigation water returns quickly to the river. However both of the ranches simulated are adjacent to the river with no fields more than a quarter mile from the river. Much of the irrigated land in the Sprague River valley lies one mile or more from the river. The Lower Sprague River Valley scale model was formulated to determine how irrigation cumulatively affects stream flow and water yield.

Five scenarios were formulated at the Lower Valley scale (see Table 38): No Irrigation, Current Conditions and Irrigation Systems, All Groundwater Source, All Sprinkler *Without* Irrigation Water Management (IWM), and All Sprinkler *With* Irrigation Water Management (IWM).

<b>Table 38: Valley Scale Irrigation Effects to Stream Flow and Water Yield.</b>					
<b>Conservation Effect</b>	<b>No Irrigation</b>	<b>Current Conditions*</b>	<b>All Ground Water Source</b>	<b>Sprinkler w/o IWM</b>	<b>Sprinkler with IWM</b>
<b>Average Annual Stream Flow (cms)</b>	16.1	15.8	17.3	15.3	15.2
<b>Annual Water Yield (cubic meter)</b>	508,042,913	497,321,603	546,528,661	483,122,466	480,350,822
* <i>Current Conditions: Irrigation Systems are comprised of 37% Sprinklers, 63% Wild flood; and the Water Source is 52% River and 48% Ground Water.</i>					

The Lower Valley model simulations show irrigation reduces stream flows and water yield from the watershed versus not irrigating. Sprinkler irrigation has the largest impact on the stream even with irrigation water management. The exception above occurs if 100 percent of the water for irrigation is pumped from ground water. Impacts to the regional aquifer from 100 percent ground water pumping irrigation were not simulated. The US Geological Survey is currently studying the regional aquifer in part to determine impacts from irrigation pumping.

*(3) Does ground water pumping for irrigation impact stream flows and ground water availability?*

As shown above, when water applied for irrigation is derived from ground water, the excess supplements stream flow and watershed water yield. This is the reason Current Conditions (with 48 percent from ground water) is only slightly less flow and yield than No Irrigation; and the All Ground Water Source (100 percent) augments stream flow and yield. Model assumptions for the Lower Valley simulations assumed pumping additional irrigation water from the regional aquifer would have no impact on ground water discharge to the river. USGS is in the process of modeling the regional ground water system in the Upper Klamath Basin. When the USGS study is completed we may know about the impact of

pumping irrigation water from the regional aquifer on ground water discharge to the river.

*(4) How does improved irrigation efficiency affect the application uniformity and the total evapotranspiration of water by plants?*

Model simulations at both the ranch and Lower Valley scales show evapotranspiration increases significantly when irrigation systems are converted from Wild Flood to Sprinkler - with Irrigation Water Management (IWM). The diagrams on pages 64-65 display the improvement in application uniformity when converting from Wild Flood to Gated Pipe to Sprinkler irrigation systems.

#### **4.2 Juniper Control and Forest Thinning**

As stated previously, conservationists hypothesize that thinning overstocked forests and clearing juniper on forest and range land could increase annual runoff and augment spring and stream flows. This CEAP study attempted to answer questions related to the relationship between juniper control/forest thinning and water.

*(1) Does forest thinning or juniper removal significantly increase stream flow?*

Unfortunately, the authors were not able to calibrate and validate the South Fork Sprague River Sub-watershed model that was developed to address this question. An un-calibrated model of historic stream flows showed only a slight increase in stream flow and water yield when juniper and Ponderosa pine forest were removed or thinned. Additional data and time for calibrating the model would provide a significantly more valid and reliable answer.

*(2) How do these practices impact soil moisture levels and surface runoff?*

Even though only one SNOTEL monitoring site existed with historic data on snow water equivalence and soil moisture, the model simulated these parameters accurately. Based on controlling juniper and thinning Ponderosa on 32,000 acres of the 82,000 acre sub-watershed, the un-calibrated model predicted a substantial increase in the amount of water available for either surface runoff to area streams or deep percolation to the regional aquifer. Again, additional data and time for calibrating the model would provide a significantly more valid and reliable answer.

#### **4.3 Wetland/Riparian Area Restoration**

*(1) How much water can be stored in the soils and for how long? (2) Is the water returned to the stream from restored wetland/riparian areas cooler and cleaner compared to the water returned under previous management strategies? (3) Does*

*riparian/wetland restoration increase sub-irrigation and forage production in adjacent meadow pastures?*

NRCS contracted with the University of Oregon to evaluate riparian/wetland restoration projects along the Sprague River (see Section 3.6). Their study revealed the importance of understanding how land management activities impact the hydrology of riparian/wetland areas. Too little or too much water can impact the success rate of restoration projects. The authors believe the MIKE SHE hydrologic model is an appropriate tool to evaluate all phases of the water budget noted as important by the University of Oregon scientists. Unfortunately, NRCS lacked data for model calibration and validation for this purpose and the time to formulate and run riparian/wetland restoration alternatives.

## 5. Future Implications

While this report closes the CEAP study, it suggests many future implications. For instance, additional research and evaluation to improve and extend the model's application in the Sprague River Watershed could be conducted. The methods and models used in this study could be applied in other areas. Information from this study could be used by NRCS and others involved in resource decisions that affect the Sprague River Watershed. Finally, this study also demonstrated how it would be possible to improve the methods and models used here for future applications.

### 5.1 Additional Research and Evaluation

Specifically in the Sprague River Watershed, researchers believe that better answers could be obtained with additional research and evaluation. Potential research results are outlined below.

Research results on the effects of irrigation could be improved by:

- More specific information on the individual landowners' level of irrigation water management and scheduling;
- More accurate identification of irrigation delivery ditches, pipelines, and takeouts;
- The use of more detailed soils information on spatial distribution and parameters, such as hydraulic conductivity, depth to an impervious layer, and water holding capacity, which is expected to become available with the completion of the on-going soil survey update;
- Better information on pasture forage species, such as rooting depths, leaf area index, and growth curves (grazed and un-grazed);
- Collection of additional regional and shallow aquifer water levels; and
- Additional water quality sampling coupled with water quality models, to improve our understanding of nutrient cycling and influences on stream temperature.

Research results on the effects of forest thinning and juniper clearing could be improved by:

- Long-term monitoring of treated and control sites to measure changes in soil moisture, water tables, spring and stream flows, canopy interception, and evapotranspiration;
- Better representation of ground water hydrology through the incorporation of results from the USGS's regional ground water study for the Upper Klamath upon its completion; and
- Validation of the MIKE SHE model at other forested sites that do have data for calibration (e.g. OSU's paired watershed study in Central Oregon).

Research results on the effects of wetland, riparian, and stream restoration could be improved by:

- Additional time to calibrate and validate the MIKE SHE/MIKE 11 model with data from out-of-bank flooding and changes in valley soil moisture and water table levels;
- Use of a complimentary 2-D channel hydraulics model (MIKE 21) that provides information such as the velocity and energy along stream banks in order to predict bank erosion and channel stability; and
- Biological information on the response of plants and animals to changes in the frequency of out-of-bank flooding and the hydro-periods for plant growth.

Recent advances in computer technology and software has made complex, robust programs like MIKE SHE possible. A model that dynamically links all parts of the hydrologic budget is able to provide researchers with an opportunity to better understand the cause and effect relationships related to the movement of water. However, the effective use of a tool such as MIKE SHE requires extensive expertise and calibration data.

## **5.2 Use of Information**

There are many potential valuable uses for the information gathered in the Sprague River CEAP study. The study has definite implications for decision making by NRCS and others in this specific watershed. It also has implications for the type of technology that can be used to answer similar questions in other watersheds.

The Sprague River Watershed has become the focus of resource concerns in the Upper Klamath River Basin. The National Academy of Science and others have pointed out the importance of this watershed for improving downstream water quality, providing habitat for endangered species, and yielding a high percentage of the annual water flow to the Upper Klamath Lake.

NRCS has the opportunity to use the information gathered in this study to establish cost-share program criteria and improve on-farm management recommendations. The State, Klamath Tribes, and individual water users could make use of the MIKE SHE model to simulate water quantity impacts from proposed changes to water rights and land management activities. State and federal wildlife agencies could use the model, along with other data being collected on stream geomorphology, fish habitat, and water quality, to design a comprehensive watershed and stream management plan.

As the irrigation research results demonstrate, conservation solutions can have conflicting resource impacts. In the Sprague River Watershed, improving on-farm irrigation efficiency could improve water quality but at the expense of reducing summer base flows. Both resource issues have been identified by one party or another as important. In order to make wise decisions that are acceptable to all parties, resource targets and priorities need to be established. This is the responsibility of many entities, not just one agency or one landowner.

During the course of this study, NRCS hosted two science meetings for researchers and project implementers to share information about the Sprague River Watershed with each other. At these meetings, all participants acknowledged the need for better communication and coordination. And, ultimately, they all supported the development of a strategic conservation implementation plan to be agreed upon by the agencies involved, the Tribes, landowners, and others. The scientific tools and approaches used in the Sprague River CEAP study, along with those used in other complementary studies, present a promising opportunity to combine the best available science with land management priorities -- and create one strategic implementation plan with support from a wide base.

### **5.3 Lesson Learned**

The CEAP program provided NRCS with a rare opportunity to intensively study and document the resource effects resulting from the implementation of recommended conservation practices. Typically, the agency has focused solely on planning, designing, and implementing conservation practices, leaving the monitoring of practices' effects to others. However, to study successfully the effects of conservation, agency scientists had to follow rigorous research methodologies.

This proved to be a learning experience for those NRCS staff involved in the Sprague River CEAP study. While the study was both challenging and rewarding, it also included its share of frustration, setbacks, and failures. Consequently, it seems appropriate to include a section in this report on "lessons learned" to, perhaps, help others who may be consider undertaking a similar effort.

Those lessons learned include the following:

- Landowners are inquisitive, willing participants, as well as, sharp observers. Involve them in your studies.
- Monitoring equipment is expensive, but lost data is irreplaceable, so protect field equipment from vandalism, cattle, weather, flooding, and other hazards. Battery-operated equipment should be replaced routinely. Solar panels should be cleaned and re-oriented to the sun each visit.
- When possible, compare manual measurements to readings from automated sensors and data loggers. Recalibrate or replace malfunctioning equipment.
- Maintenance of equipment is essential but becomes difficult to conduct regularly if local staff are not available.
- Count on downloading field data to take three times as long as you think it will.
- While in the field, keep a checklist of the tasks you need to perform and refer to it often.
- If you are uncertain about monitoring equipment, methodologies, or your interpretation of results, seek help. Often there are others who have faced the same problems and can help.
- Share your results with other researchers and do it often.

This study, as with most research, could be improved through the investment of more time and money, though there is no guarantee that the benefit would be worth the cost. Computer models are not the panaceas for all resource questions. The following are a few pros and cons we found in using the MIKE SHE/MIKE 11 hydrologic model.

Pros:

1. The use of a robust model that simulates the entire water budget throughout the year.
2. The model adequately simulates irrigation.
3. With the model being physically and geographically based, means the parameters that physically change with land management activities can be adjusted in the simulation, such as leaf area index, canopy interception, etc., rather than requiring the researchers to estimate the change of a lumped parameter, such as curve numbers.
4. It is one of only a few models that can simulate land management impacts to stream base flows.
5. The model is capable of simulating the dynamic interaction between surface and ground water systems.
6. MIKE SHE belongs to a suite of Danish Hydrologic Institute (DHI) hydrologic models and extensions that can be linked for additional analyses. These include such elements as 2-dimensional channel hydraulics, pipe hydraulics, basin scale hydrology, water quality, sediment transport, plant growth, and flooding.

Cons:

1. It is proprietary software with costs for licenses and maintenance.
2. Technical support from DHI is essential, but the company has limited staff in the United States.
3. Few individuals other than DHI staff currently have the necessary expertise in using the software.
4. A steep learning curve will take anyone new to the software considerable time before they can effectively use the model.
5. The cost for model robustness is increased computation time (a three-year simulation with a three-hour time step for a 40,000 acre watershed can take 12 hours or more to run.)
6. The model limits on the number of grid cells representing spatial domain which forces poor model resolution and generalization of the landscape.
7. MIKE SHE/MIKE 11 is relatively new software that still has bugs and undocumented quirks.

Lastly, studies of this nature are and need to be multi-year efforts. The Sprague River CEAP study began four years ago. Over this length of time, however, it proved difficult to maintain continuity in staff and work priorities. Of the original six NRCS staff involved in this study, two retired, and one transferred to a different job location, and two left NRCS for positions in the private sector. Only the staff supervisor remained in place. Agencies such as the Agricultural Research Service may be better suited to conduct in-



depth studies; however, NRCS's unique relationship with landowners, Tribes, NGOs, and other resource agencies allowed NRCS to keep study objectives pertinent and local participants involved.

## **6. Report Authors, Contributors, and Acknowledgements**

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### **Contributors:**

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## 7. References and Notes

- <sup>1</sup> Danish Hydraulic Institute, <http://www.dhigroup.com/>
- <sup>2</sup> Upper Klamath Lake Basin Nutrient-Loading Study-Assessment of Historic Flows in the Williamson and Sprague Rivers, USGS, Water-Resources Investigations Report 98-4198.
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- <sup>9</sup> DHSVM, University of Washington, <http://www.hydro.washington.edu/Lettenmaier/Models/DHSVM/index.shtml>
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- <sup>15</sup> Oregon Department of Water Resources, Water Rights Information System, 2007 <http://www.wrd.state.or.us/OWRD/WR/>
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<sup>20</sup> Gannett, M.W., Lite, K.E. Jr., La Marche, J.L., Fisher, B.J., and Polette, D.J., 2007, Ground-water hydrology of the upper Klamath Basin, Oregon and California: U.S. Geological Survey Scientific Investigations Report 2007-5050, p. 84.

<sup>21</sup> USGS, Preliminary Assessment of Nutrient Dynamics in the Sprague River Subbasin, Administrative Report, Kathleen A. McCarthy, 2006.

<sup>22</sup> The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance (“noise”) compared to the measured data variance (“information”). NSE ranges between negative infinity and 1.0, with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicate that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

<sup>23</sup> Field Inventory conducted by NRCS, 2005.

<sup>24</sup> Oregon Department of Water Resources, Water Rights Database, 2007, <http://egov.oregon.gov/OWRD/>.

<sup>25</sup> For this study, “without irrigation water management (IWM)” assumes an application of 3 acre-feet of water per acre.

<sup>26</sup> “With IWM”, assumes irrigators by correctly scheduling their irrigation can meet crop water requirements by applying only 2 acre-feet of water per acre.

<sup>27</sup> Water Year from October 1 through Sept 30; Irrigation Season from June 1 to October 20; Wet Season from October 21 to May 31.

<sup>28</sup> A water quality module is available with the MIKE SHE software but was not used in this study. Future work could incorporate water routines to determine how different irrigation scenarios impact both nutrient and temperature loading in the stream.

<sup>29</sup> For more information on the Camp Creek Paired Watershed Study contact Tim Deboodt, OSU Extension, <http://oregonstate.edu/dept/range/faculty/deboodt>.

<sup>30</sup> “Biology, Ecology and Management of Western Juniper”, Oregon State University Agricultural Experiment Station, Technical Bulletin 152, June 2005.

<sup>31</sup> The dynamics of rainfall interception by a seasonal temperate rainforest, Link, Unsworth, & Marks, *Agricultural and Forest Meteorology* 124 (2004)

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