RECLAMATION

Managing Water in the West

Natural Flow of the Upper Klamath River

U.S. Department of the Interior
Bureau of Reclamation

November 2005

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover photo by J. Rasmussen— McCornac Point Marsh

Natural Flow of the Upper Klamath River—Phase I

Natural inflow to, natural losses from, and natural outfall of Upper Klamath Lake to the Link River and the Klamath River at Keno

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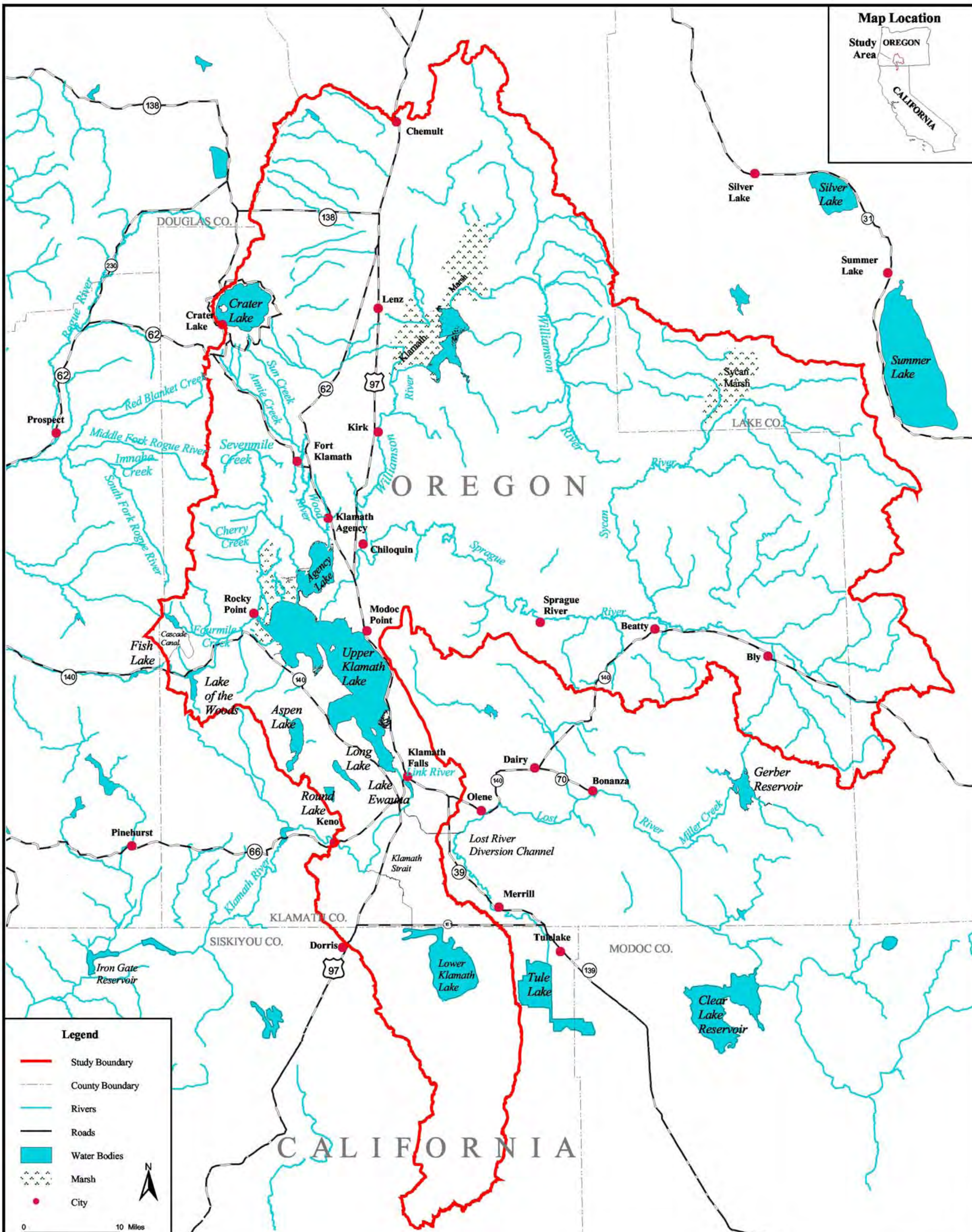
U.S. Department of the Interior
Bureau of Reclamation
Klamath Basin Area Office
Klamath Falls, Oregon

November 2005



Base map and study area.

Preface

This study was undertaken to estimate the effects of agricultural development on natural flows in the Upper Klamath River Basin. A large body of data was reviewed and analyzed to obtain the results included in this assessment of the natural hydrology of the Basin.

Within this report, the term natural represents typical flows without agricultural development in the basin. The term predevelopment describes watershed conditions existing during the pre-settlement period which ended in the mid-19th century. The last vestige of predevelopment watershed conditions unaffected by agricultural development was probably gone by about 1960. Changes in forest conditions and land-use management activities were considered but not addressed in this study. Only within remote alpine and some sub-alpine watersheds are present-day environmental conditions similar to those that existed before settlement began.

A draft of this report was released for review and comment in December 2003. The report was reorganized and additional explanations and elements were added in December 2004 based on the comments received from the reviewers of the December 2003 draft report.

During early 2005, a workgroup representing an array of Klamath Basin interests was convened by Reclamation. In three workgroup meetings (March 2-3, 2005, and April 26-27, 2005, and September 1-2, 2005), several technical aspects of the natural flow study were discussed and review comments were offered by the workgroup on the December 2004 report. Comments on the December 2004 report were documented in a comment/response matrix prepared by Reclamation's Klamath Basin Area Office. This November 2005 report incorporates research of additional data recently collected.

The Excel® model spreadsheet application, input and output files, and results are included in the CD which contains this report and all its attachments.

Acknowledgments

Many valuable, insightful, and objective comments and suggestions have been provided by reviewers of this work, especially the following, in alphabetical order:

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Acronyms and Abbreviations

cfs	Cubic feet per second
CU	Consumptive use
EP	Effective precipitation
ET	Evapotranspiration
GIS	Geographic Information System
LKL	Lower Klamath Lake
MAD	Minimum absolute deviation
Net ET	Net consumptive use
NOAA	National Oceanic and Atmospheric Administration
OWRD	Oregon Water Resources Department
USDA	U.S. Department of Agriculture
FS	Forest Service (in USDA)
UKL	Upper Klamath Lake
USGS	U.S. Geological Survey
USRS	U.S. Reclamation Service

Executive Summary

This report presents details of the investigation and results in estimating the natural flow of the upper Klamath River at Keno, Oregon. The area investigated includes the Klamath River Basin above Keno, Oregon, primarily in Klamath County, with some areas of Siskiyou and Modoc Counties in California. The study area includes the Sprague, Williamson, and Wood River basins, as well as Upper Klamath and Lower Klamath Lakes.

Objectives

The current purpose of this study is to provide an estimate of the monthly natural flows in the upper Klamath River at Keno. This estimate of the natural flow represents typical flow without agricultural development in the Upper Klamath River Basin, including its tributaries.

Study Approach

This study used a water budget approach to assess the agricultural depletions and alterations to the natural flow. The approach was to evaluate the changes of agriculture from predevelopment conditions, estimate the effects of these changes, and restore the water budget to natural conditions by reversing the effects of agricultural development. Records used in this empirical assessment were derived from both stream gaging flow histories and from climatological records for stations within and adjacent to the study area.

Water Budget Description

The water budget assessment of the watershed as a natural system includes an evaluation of hydrological changes related to agricultural development above the Keno gage. The water budget assessment includes:

- Natural inflow from the Sprague, Williamson, and Wood Rivers to Upper Klamath Lake
- Predevelopment evapotranspiration losses from marshes surrounding Upper Klamath Lake
- Predevelopment evaporation losses of the Upper Klamath Lake
- Natural flow at the outlet of Upper Klamath Lake into the Link River at Klamath Falls
- Resulting natural flow at Keno

The processes developed in the water budget to evaluate the natural outflow of Upper Klamath Lake accounts for factors related to water resources developments in the watershed that have affected inflow to the lake, and for losses due to natural condition of the lake. The water budget assessment of the watershed as a natural system includes an evaluation of hydrological changes related to agricultural development above the Keno gage.

The results of the water budget assessment are given as average annual flows for two important stream gages, one located on the Link River at Klamath Falls and the other on the Klamath River at Keno.

Evaluation of Predevelopment Conditions

An evaluation of predevelopment conditions included an evaluation of changes to Upper Klamath Lake, agricultural developments in the Wood River, Sprague River, and Williamson River watersheds. Several basic elements were considered in this study:

- How had development changed the system
- Was information available about conditions before the changes occurred
- Were data available to assist in estimating changes to the natural system

Evaluation of Current Conditions

Period of Record

The period of record considered in this investigation is the 52 years from 1949 to 2000. This period of record was chosen because hydrologic and climatological data were limited for the pre-1949 period and data beyond 2000 were not available when the study began. The water year convention (October through September) is used in this report.

Crop and Marshland Evapotranspiration Analysis

The modified Blaney-Criddle method was used to determine potential net evapotranspiration (ET) from crops, marshlands, and riparian zones. The method is empirical and the calculated values were adjusted based on other recent study findings and water limiting considerations. To estimate net ET water consumption by this method requires the following data:

- Location of irrigated lands, marshlands, and riparian zones
- Types of crops and number of acres for each crop
- Types and acreages of marshland and riparian vegetation, both existing and predevelopment
- Monthly precipitation and monthly average temperature for the period of record for each area

Methods to Estimate Natural Flows

Natural streamflow development included adjustment of gaged streamflow to natural flow, restoration of missing streamflow and climate data, making natural streamflow estimates in ungaged watersheds, assessing groundwater contributions, and estimating transit losses. Not all of these procedures were appropriate or possible in all subbasins of the study area.

Records of historic flow may be adjusted to natural flow using crop net consumptive use and marshland evapotranspiration:

natural flow = gaged flow + crop net consumptive use – reclaimed natural marshland net evapotranspiration

Correlation analysis was used to restore missing values from monthly-value data records used in this study. The method is different from linear least-squares regression estimation. Data records used in this study include precipitation and average temperature histories, in addition to hydrologic records of streamflow and lake stage.

Also, natural streamflow histories are required in ungaged watersheds to assess the natural inflow to Upper Klamath Lake. Sparse monthly flow records for streams heading on the east flank of the Cascades and flowing into the Wood River Valley or Pelican Bay area of Upper Klamath Lake required estimation techniques that used gaged histories from nearby river basins. These data were evaluated in statistical applications to yield natural flow estimates for these ungaged portions of the Klamath Basin.

In a similar vein, groundwater contributions required temporal adjustments attributable to the climate signature evident in longer term records for similar groundwater discharges in neighboring watersheds. Transit losses for both surface water and groundwater contributions were also estimated in this study.

Natural Lake Simulations

Implementation of a water budget for Upper Klamath Lake required developing information about (1) the storage and inundation surface area characteristics of the lake, and (2) the discharge characteristics at the outflow point of the lake. These characteristics were evaluated in relation to the elevation, or stage, of the water surface of the lake. Additionally, discharge from the lake was also related to the stage.

Estimating the outflow of a natural lake is accomplished using a water budget approach. A monthly summation of all elements in the water budget may be stated by the general form of the hydrologic equation:

$$i = o + \Delta s$$

where

i = inflow to the lake
o = outflow from the lake

and

Δs = change in storage of the lake

For Upper Klamath Lake, the month-to-month water budget accounts for natural inflow, storage of water within each lake, resulting estimated lake stage, and discharge from each lake. In addition, open water surface evaporation and groundwater discharge to the lake from the regional aquifer were estimated. The water budget assessment was designed to simulate the lake as a natural water body.

Materials and Data Researched and Used

Data Sources

Records used in this analysis were derived from both stream gaging flow histories and from climatological records for stations within and adjacent to the study area. Information was also developed from published reports, file documents, and maps. Supporting information included documents from:

- Archives of the Bureau of Reclamation Klamath Basin Area Office
- Numerous U.S. Geological Survey (USGS) Water Supply Papers regarding stream gaging records
- Compact disk databases containing digital records of gaged flow, lake stage records, and meteorological data

Anecdotal items from newspaper articles or clipped from magazines were also reviewed. These sources consisted of narratives of past events or conditions, transcripts of interviews, newspaper accounts, books, diaries, and historical journals. These provided an impression of predevelopment conditions that can be compared to the empirical and scientific information gleaned from other sources. Other reviewed materials included unpublished and out-of-print scientific reports, historical maps, letters, books, journals, and photographs.

Modeling Tools

Results of the water budget assessment were accomplished using Excel®, a sophisticated spreadsheet available in the Microsoft Office for Windows software package. This model was chosen over other models because this study is unique. The computational modules built as the study developed represent a custom application of Excel® to the solution of estimating the natural flow conditions in the Upper Klamath River Basin.

Klamath River at Keno Gaging Station

For the simulation period, 1949 to 2000, the water balance for the Upper Klamath River Basin at Keno is described below. The natural outflow (discharge) from Upper Klamath Lake at Link River was computed in the water balance. Discharge at Keno was then calculated using a correlation relationship developed between historic measured Link River and Keno flows. Table S-1 presents the estimated water balance and outflow developed for the Link River and Keno gages.

Table S-1. Estimated inflow and outflow developed for Link River and Keno gages

Upper Klamath Lake		Acre-feet
	Average annual natural inflow	1,605,000
	Average annual natural net loss	210,000
	Resulting average annual natural outflow	1,395,000
Link River to Keno		
	Average annual natural inflow	1,485,000
	Resulting average annual natural outflow at Keno gage	1,306,000

Other Factors Considered

The focus of this study is agricultural development in the Upper Klamath River Basin and its effects on natural flow conditions. Other watershed factors have changed since predevelopment. Some of these factors were considered, but are unaccounted-for in the assessment, such as changes in forest conditions or an extension of the flow histories before 1949.

Model Review and Sensitivity Analysis

Although this study uses best available hydrologic methods and data to either measure or estimate all inflows and outflows to the system, additional concerns have arisen in completing the work.

Relationships regarding the significance of uncertainty are likely to be spatially and temporally variable. The key factor is the relative importance of each module in the transit losses suffered by inflows to the natural system. The significance of these influences to model sensitivity is related to time of year or length of time over which flows are evaluated. Model sensitivity is related to uncertainty in data regarding the most significant transit losses; namely, marsh evapotranspiration and open water evaporation.

The natural flows developed at Keno are realized, in part, through a statistical rule based model rather than a physically based model. This construct within the model is for the segment from the Link River gage below Upper Klamath Lake, to the Keno gage below Lower Klamath Lake. Thus, sensitivity in testing the spatial and temporal variables within the Link River to Keno reach that affect the flow at Keno is problematic.

Summary

Development of the natural flows at the Keno gage was accomplished using a spreadsheet modeling approach to resolve the water budget for the Upper Klamath River Basin under undeveloped watershed conditions. The resulting flow duration for simulated natural average monthly flows for Keno gage are described in Table S-2. The percentiles represent the flow exceedence ranges in monthly natural flow estimates at Keno solely due to record length. These percentiles are estimates for modeled baseline conditions and do not reflect data uncertainties for possible changes in evaporation, evapotranspiration, or other factors.

Table S-2. Summary of simulated monthly flows at Keno in cfs

% Time <=	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Annual	% Time >=
10	648	1088	1216	1408	1647	1577	1670	1408	1168	631	520	560	1188	90
20	769	1159	1352	1472	1767	1689	2017	1721	1358	822	578	616	1429	80
30	857	1255	1453	1667	1925	1907	2125	2051	1664	964	706	720	1528	70
40	974	1342	1625	1845	2016	2040	2477	2280	1890	1228	767	746	1607	60
50	1033	1455	1698	1964	2343	2133	2595	2649	2039	1349	873	854	1773	50
60	1131	1523	1803	2072	2410	2360	3009	2827	2388	1478	998	955	1903	40
70	1224	1576	1984	2196	2615	2703	3146	3131	2657	1706	1154	1049	2169	30
80	1304	1739	2049	2399	2829	3115	3615	3385	3104	2210	1351	1210	2347	20
90	1488	1815	2319	2659	3294	3367	3877	3707	3460	2923	1684	1412	2511	10

A simplified flowchart depicting the overall sources of included inflow and outflow variables has been completed as figure S-1, with average annual values shown from each source.

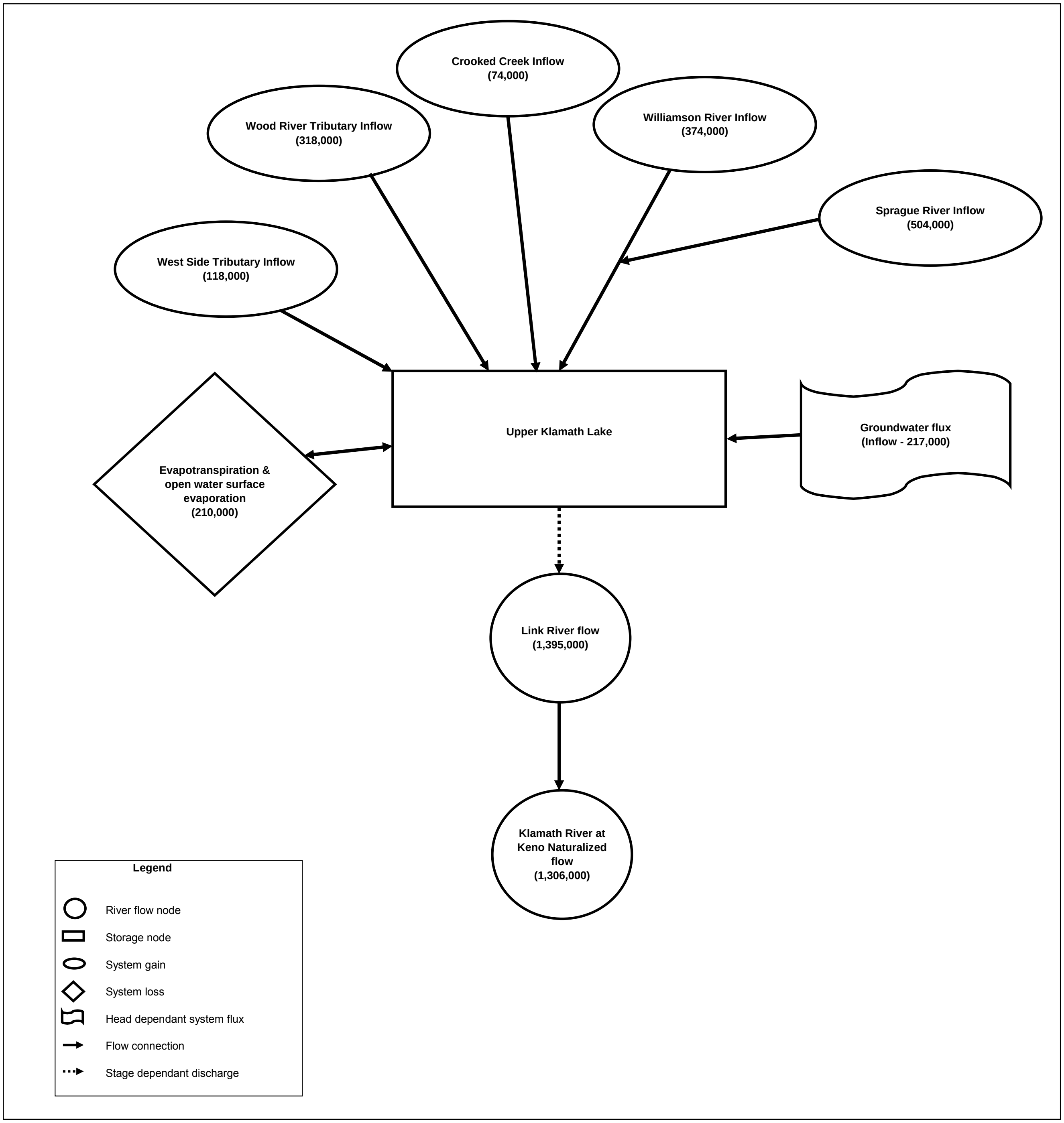

Figure S-1. Simplified flowchart of how natural flows were estimated with average annual values shown.

Chapter 1 —
General Overview

This report presents details of the investigation and results in estimating the natural flow of the upper Klamath River at Keno, Oregon.

Purpose and Scope

The current purpose of this study is to provide an estimate of the monthly natural flows in the upper Klamath River at Keno. This estimate of the natural flow represents typical flow without agricultural development (and its related water resources developments) in the Upper Klamath River Basin, including its tributaries. Municipal, industrial, and rural domestic water uses were not accounted for in this analysis. Forest practices were also considered but not accounted for in developing natural flows.

Recognizing the agricultural scope of this estimate of the natural flow of the upper Klamath River, the results of this study may be useful in determining agricultural development's role in basin issues.

Measured flows were used, where available, in developing this study; however, a comparison of measured flows to the estimated natural flow is outside the scope of this study. Also, the hydrologic model developed in this study has not been compared or contrasted to other Klamath Basin studies (e.g., Phillip Williams & Associates/KPSIM, Balance Hydrologics, and CH2MHill studies).

Study Area

The area investigated includes the Klamath River Basin above Keno, Oregon, primarily in Klamath County, Oregon, with some areas of Siskiyou and Modoc Counties in California. The study area includes the Sprague, Williamson, and Wood River basins, as well as Upper Klamath and Lower Klamath Lakes.

Geologic and Physiographic Features

The study area is the natural Klamath Basin above Keno, which encompasses about 4,250 square miles or 2.7 million acres and is part of the East Cascades Ecoregion (ecoregion) that spans the eastern slope of the Cascade mountain range from south central Washington to northern California. The ecoregion as a whole is characterized by volcanic geology (basalt flows and ash and pumice deposits) dominated by pine forests. Elevations in the basin range from elevation 3800 to about 9500 feet above sea level. The remaining lands form the northernmost part of the Great Basin, a semi-arid high desert plateau averaging 4000 to 6000 feet in elevation.

The hydrology of the Upper Klamath River Basin has a complex history. Upper Klamath Lake is one of the few surviving Pliocene (about 5 million years ago) lakes and perhaps the only functional Pliocene lake, with normal alkalinity and a large relict fauna in the ecoregion (Newcomb and Hart, 1958; Leonard and Harris, 1974).

Between 1905 and the 1960s, wetlands in the Upper Klamath River Basin were reduced from 350,000 acres to 75,000 acres (an 80 percent reduction) as these areas were drained, diked, and converted to agriculture.

About 70 percent of Klamath County is forested. More than half of the land is publicly owned (56 percent), with 44 percent of these public lands in the national forest. The area's diverse landscape supports a great variety of biological communities. The eastern slopes of the Cascades host abundant fir forests, while pine and juniper thrive on the ridges of the east plateau.

Climate

The climate of the basin is characterized by relatively dry summers with moderate temperatures and winters with moderate to low temperatures. About two-thirds of the precipitation falls as snow between October and March (Climatological Data Oregon State Climatologist, National Weather Service.) Total average snowfall at Klamath Falls is about 41 inches. Crater Lake receives about 521 inches of snow annually. Average precipitation ranges from as little as 10 inches in the basin to more than 70 inches in the mountains. The mean yearly precipitation from 1961 to 1990 was 13.5 inches as measured at Klamath Falls, Oregon. Figure 1 presents average precipitation across the study area.

Killing frosts have been recorded throughout the basin in every month of the year. Growing seasons range from 20 to 40 days at higher elevations to 100 to 125 days in the lower valleys. Thus, climate is the major limitation on the variety of crops which may be grown in many areas of the basin.

Water Supplies

Rivers flow through the region's many river basins and valleys and are detained occasionally by sizable lakes and marshes. Figure 2 shows the hydrologic basins within the study area. These fresh water lakes include Upper Klamath Lake, Lake Ewauna, Lake of the Woods, and Agency Lake. Crater Lake is 62 miles northwest of the city of Klamath Falls. It lies within the rim of a dormant volcano and at nearly 2,000 feet deep, it is the deepest lake in the United States.

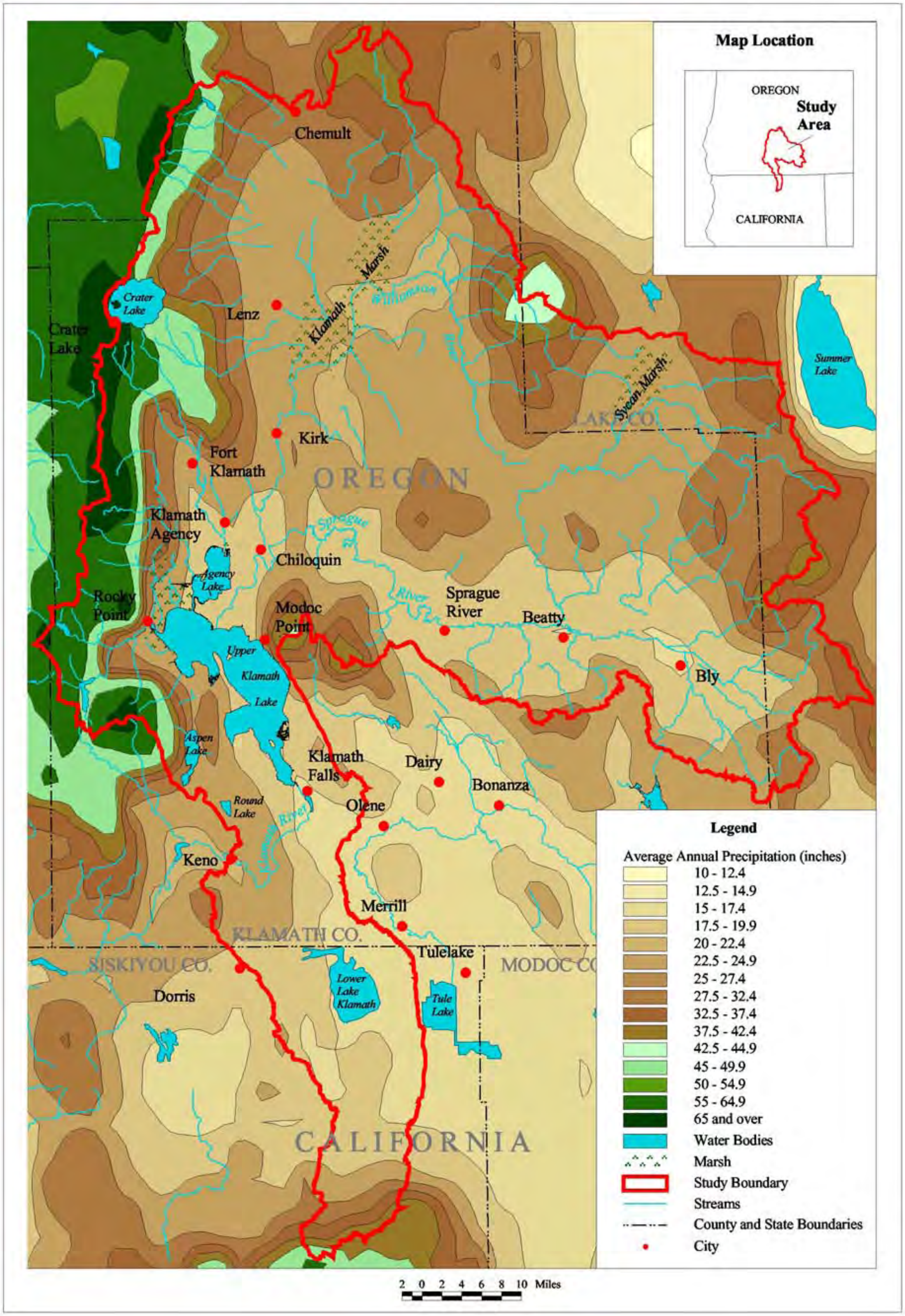

Figure 1. Average annual precipitation within the study area.

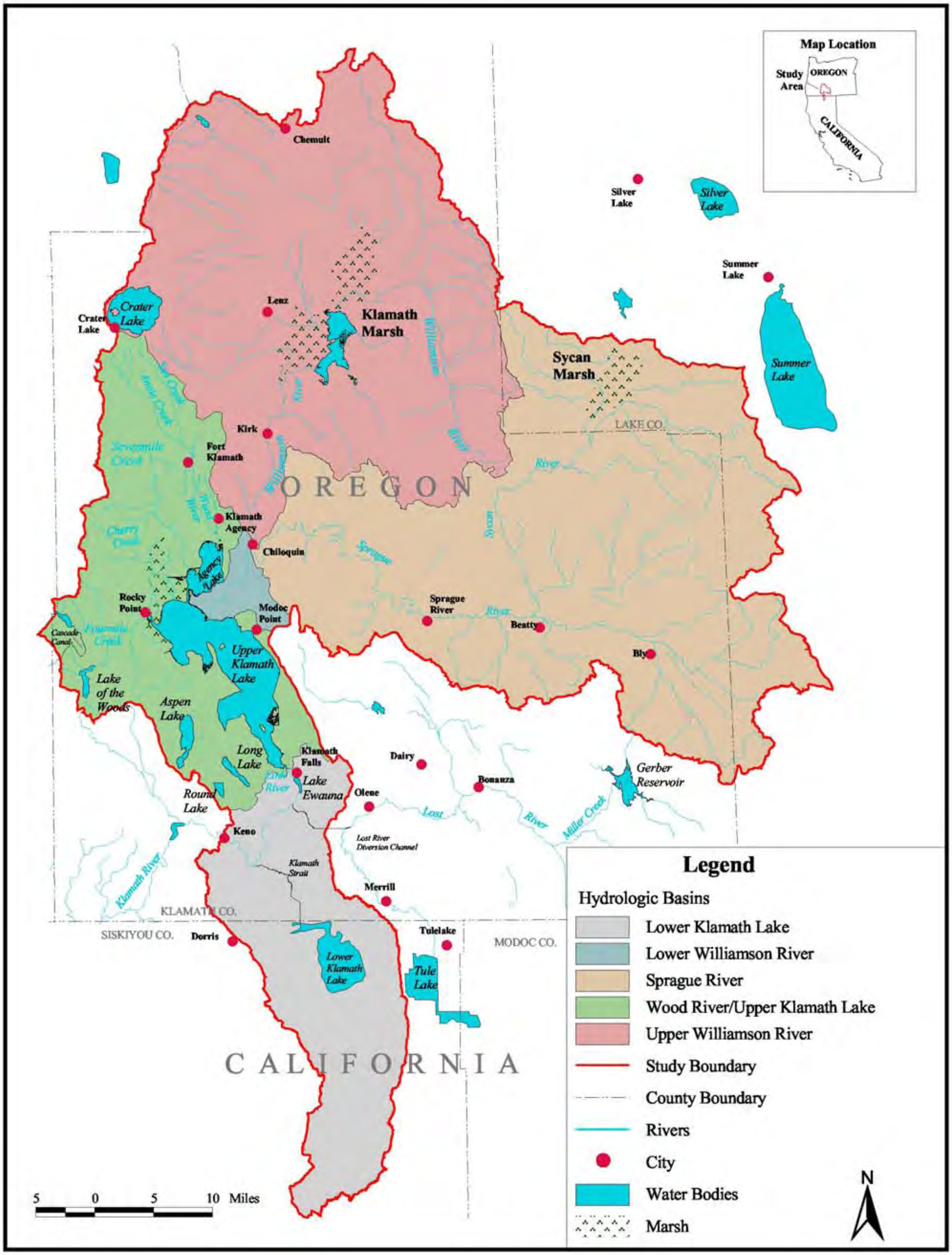

Figure 2. Hydrologic basins within the study area.

Upper Klamath Lake

Upper Klamath Lake is a large, shallow hypereutrophic (high biological productivity) lake with extensive wetlands, numerous shoreline springs, and several tributaries. This lake is the largest body of fresh water in Oregon and varies from 6 to 14 miles wide and is about 25 miles long. Upper Klamath Lake has a surface area of approximately 64,000 acres and a total capacity of more than 650,000 acre-feet. The operational capacity is approximately 486,800 acre-feet. Net inflow for the entire year averages 1.2 million acre-feet but ranges from 576,000 to 2.4 million acre-feet.

The Sprague River is tributary to the Williamson River, which empties into Upper Klamath Lake and drains the central and eastern part of the Upper Klamath River Basin. The Upper Klamath Lake empties to the Link River. The Klamath River begins at Lake Ewauna just south of Upper Klamath Lake and flows southwest into California. Flow for the entire Upper Klamath River Basin is recorded at the Klamath River gage at Keno, Oregon.

Lower Klamath Lake

Lower Klamath Lake, which was once directly connected with the Klamath River, has largely been drained, and the remaining marsh and lake areas are now managed primarily as Lower Klamath National Wildlife Refuge. Maintained primarily for waterfowl and water dependent species, this 53,600 acre refuge contains 12 wetland units that are supplied with water on either a seasonal or a permanent basis. Unit 2 (about 2,200 acres), with an average depth of about 3 feet, is the only unit that is maintained as a permanently flooded lake. Private agricultural lands are within the boundary of the former lake, as well.

Groundwater

Near Chiloquin, Oregon, the subsurface geology consists of lake deposits with interbedded alluvial deposits of sands, clays, and silts. These lake deposits generally do not produce substantial yields to wells in other areas of the Upper Klamath River Basin. Volcanic rocks underlie the lake deposits, and these rocks have produced moderate to high yields for wells in other areas of the basin. Wells in some locations may have to be drilled to a depth of between 700 and 1,000 feet (or greater) to reach this water-bearing volcanic zone. Groundwater, however, does discharge into streams flowing into Upper Klamath Lake, and also into the lake itself. This discharge is noted as substantial.

Study Approach

Water Budget Description

This study used a water budget approach to assess the agricultural depletions and alterations to the natural flow of the Upper Klamath River Basin. Figure 3 shows a sketch of the current conditions and types of changes that have occurred in the basin.

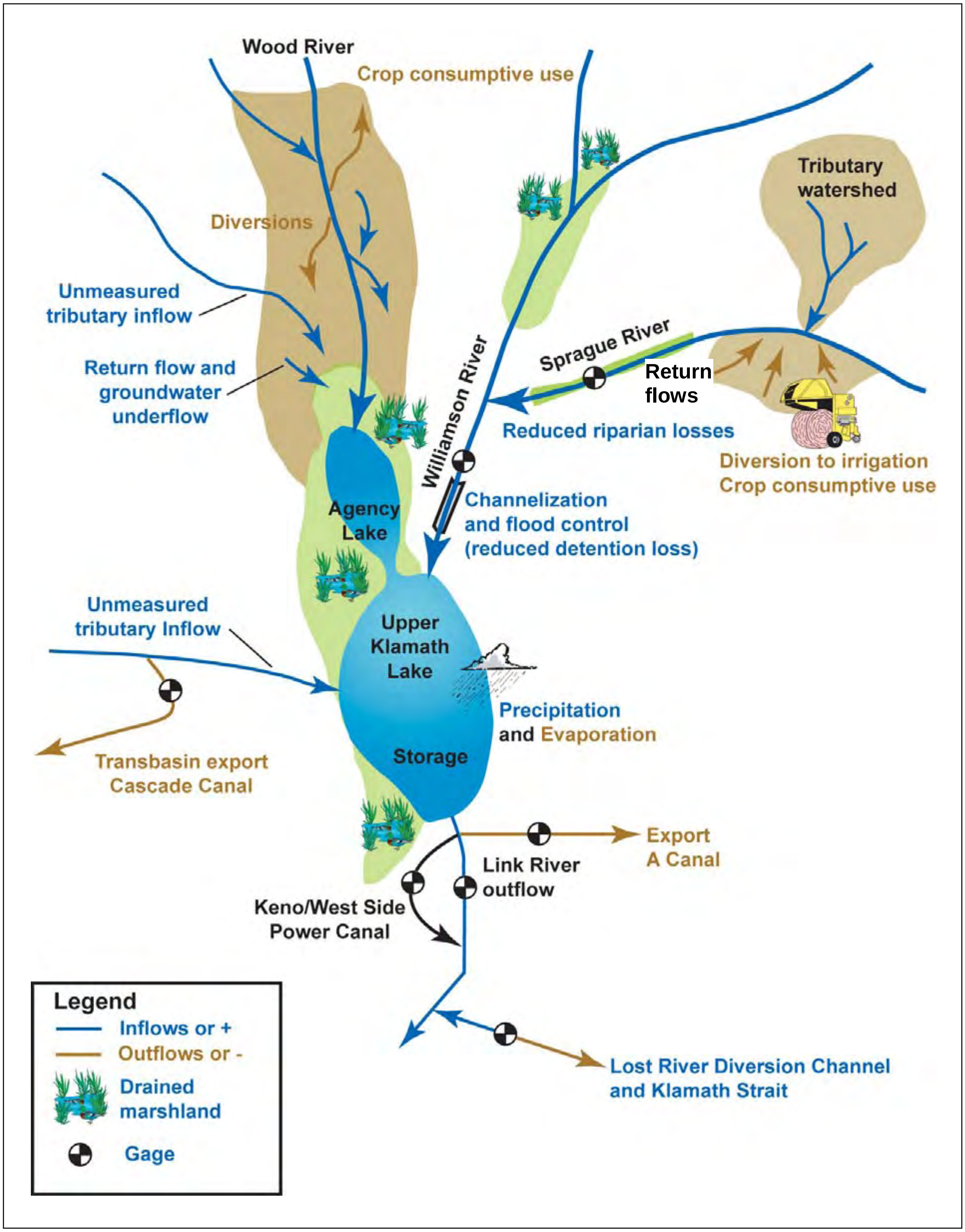

Figure 3. Sketch of the current conditions and types of changes that are addressed in this study.

In Figure 3, changes in streamflow because of current conditions are indicated by blue for gains (+) in flow or tan for losses (-) in flow. Generally, the water budget + and - factors in the watershed above the lake must be reversed to determine natural inflow to the lake. The water budget must consider unaccounted natural losses reclaimed by development, as well. Assessment of Upper Klamath Lake as a natural water body and determination of natural flow at Link River requires simulation of the lake based upon the determined natural inflow tributary to the lake for a chosen period of record, and the dynamic changes in lake storage, marsh evapotranspiration, and water surface evaporation that would have occurred under natural conditions. The water budget accounts for:

- Natural inflow from the Sprague, Williamson, and Wood Rivers to Upper Klamath Lake
- Predevelopment evapotranspiration losses from marshes surrounding Upper Klamath Lake
- Predevelopment evaporation losses of the Upper Klamath Lake
- Natural flow at the outlet of Upper Klamath Lake into the Link River at Klamath Falls
- Resulting natural flow at Keno

Integration of temporal and spatial data occurred for individual components of the water budget for the natural flows. Evapotranspiration from irrigated fields and marshes and evaporation from the lakes had to be quantified for a water budget accounting of processes. These elements were determined using selected procedures that could be applied using available data.

Results of the water budget assessment were accomplished using Microsoft Excel®. The computational modules were built as the study developed and represent a custom application of Excel® to the solution of estimating the natural flow conditions in the Upper Klamath River Basin.

The water budget in Excel® is a numerical simulation based on a detailed month-to-month water budget of processes occurring in Upper Klamath Lake. The precision of the values reported on the calculations tab of this spreadsheet, and other tabs, exceeds the reliable accuracy of the estimates. Figure 4 presents a flow chart of how the natural flows were estimated.

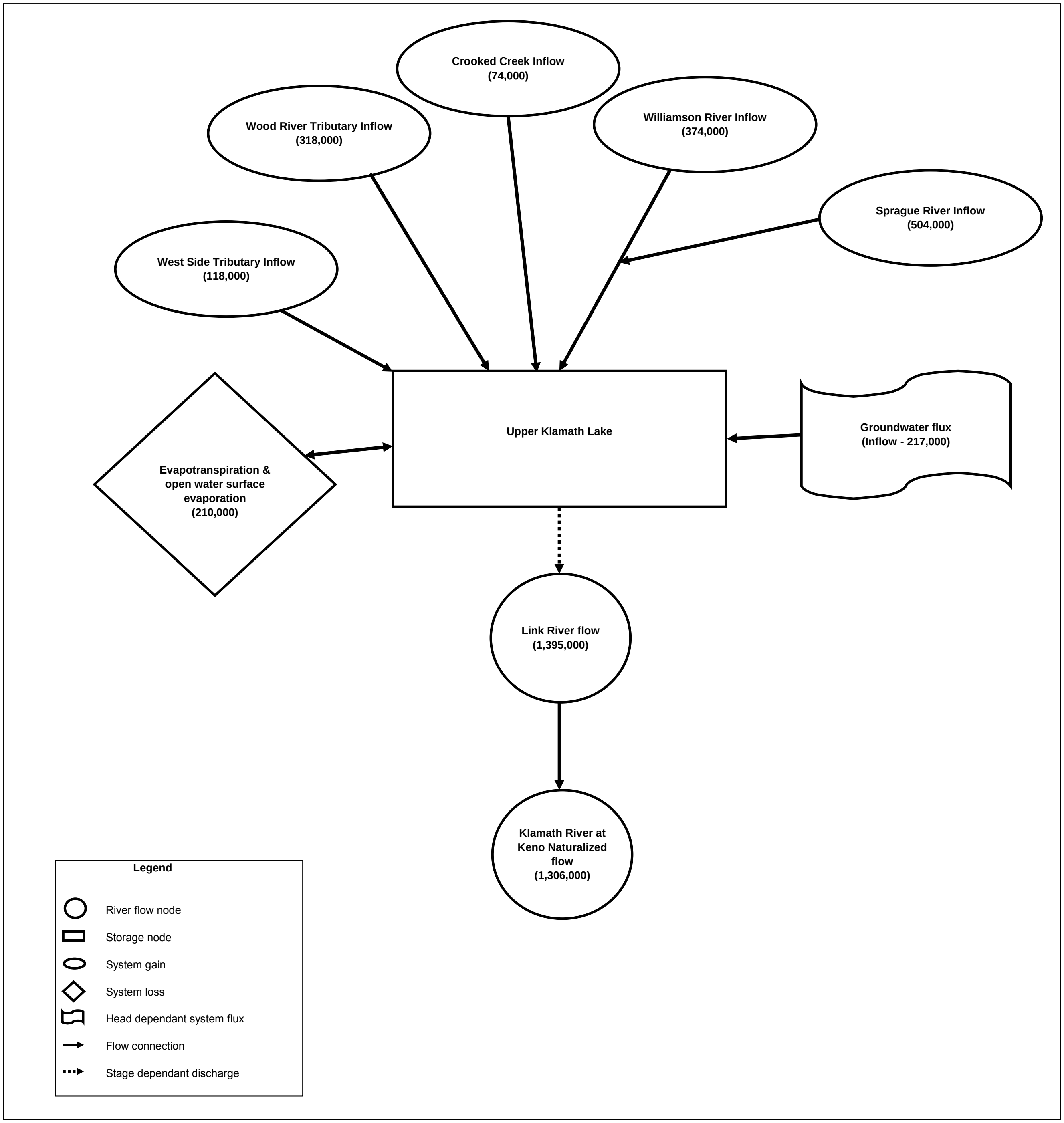

Figure 4. Simplified flowchart of how natural flows were estimated.

Evaluation of Predevelopment Conditions

The evaluation of the natural flow conditions within the Upper Klamath River Basin began with a description of the predevelopment condition. Several basic elements had to be considered.

- How had development altered the system being evaluated
- Was information available regarding conditions before these changes were implemented
- What data were available to assist in estimating changes to the natural system

Additional past watershed and lake conditions were obtained through searches of the Shaw Historical Library at the Oregon Institute of Technology, the Klamath County Museum, and the State of Oregon Water Resources Department. Many of the items reviewed were from newspaper articles or clipped from magazines. As such, much of this material was anecdotal, consisting of information in narratives of past events or conditions, such as transcripts of interviews, newspaper accounts, books, diaries, and historical journals. Examples of sources of anecdotal information include the Shaw Historical Library's journal *Klamath Echoes*, the *Klamath Republican* and *The Evening Herald and News* newspapers, and sections of *50 Years on the Klamath* by J.C. Boyle. By reviewing a wide variety of anecdotal sources, an impression of preproject conditions was gained, which was an adjunct to the empirical and scientific information gleaned from other sources.

Reviewed materials also included unpublished and out-of-print scientific reports, historical maps, letters, books, journals, and photographs. Historical topographic maps and previous studies were used to determine the extent of marshlands around the historical natural Upper and Lower Klamath Lakes as these lakes existed at the end of the predevelopment era.

Construction drawings helped establish the preproject configuration of the reefs at the outlet of Upper Klamath Lake and in the Klamath River near Keno, and Reclamation records and USGS water supply papers provided predam water surface elevations and discharges at key locations as well as anecdotal information about gage problems and accuracies. Historical photographs are also considered empirical evidence of past conditions. Good examples are the several photographs of the Link River area before construction of the Link River Dam.

In addition to document reviews, reconnaissance trips verified current field conditions. For example, an examination of the field area was completed for the Wood River Valley in early August 2002. At this time, the major portions of the field area of the Sprague and Williamson Rivers watersheds were also examined.

Maps and historical documents are important temporal and spatial data to document predevelopment conditions. Predevelopment field conditions were documented using late 19th and early 20th century maps published by the USGS and U.S. Reclamation Service (USRS). Mapped Geographic Information System (GIS) coverage documenting the locations and areas of irrigated lands was obtained electronically from the State of Oregon. Maps, reports, and articles documenting predevelopment (i.e., frontier) field conditions were reviewed, as published by the sources listed in Table 1.

Evaluation of Current Conditions

Data Sources

Current conditions of the watershed were ascertained through file records and other information available from the Klamath Basin Area Office, including water records, reports, maps, and aerial photographs. Information regarding irrigation practices, land use, meteorological and streamflows were obtained from the National Oceanographic and Atmospheric Administration, publications of the National Weather Service, water supply papers and other publications of the USGS, and the USGS data published on compact disks by Hydrosphere, in Boulder, Colorado. Some stream gaging records were acquired electronically from Oregon Water Resources Department (OWRD).

Period of Record

The period of record considered in this investigation is the 52 years from 1949 to 2000. This period of record was chosen because hydrologic and climatological data were limited for the pre-1949 period and data beyond 2000 were not available when the study began.

Crop and Marshland Evapotranspiration

Changes to the natural condition of Upper Klamath Lake were evaluated by estimating vegetation changes around the lake. Before 1890, plane-table surveys of areas comprising 1:250,000 scale quadrangles covering Upper Klamath Lake had been completed by the U.S. Geological Survey. An updated compilation of these quadrangles was published in 1906 by USRS. Also analyzed was a planimetric map from LaRue (1920 and 1922) that was based on a 1916 plane-table survey by the USRS. The maps from both these sources were used to assist in evaluating the extent of the open water surface area and to identify natural marshlands and other changes associated with predevelopment conditions for Upper Klamath Lake. The more detailed 1:24,000 scale plane-table survey that the Reclamation Service completed in 1916 was used as the primary source of information for this evaluation. Thus, evaporation from the lake surface and water used by natural marsh vegetation were estimated. The estimated groundwater inflow to the lake from the regional aquifer was also considered. The natural flow of the Link River was computed as the resulting natural outflow from Upper Klamath Lake from the water budget calculations.

Table 1. Maps, reports, and articles that document predevelopment conditions

United States Geological Survey
1:250,000 scale sheets mapped by plane-table methods, late 1880s Ashland, Klamath, Modoc (predevelopment conditions)
Twenty-first Annual Report of the United States Geological Survey to the Secretary of the Interior, 1899 – 1900. Part V, Forest Reserves, Cascade Range and Ashland Forest Reserves, Oregon. John B. Leiberg. Washington, District of Columbia. p. 209, ff., inclusive of Plates 71 and 72. (predevelopment conditions)
Nitrogen and Phosphorous Loading from Drained Wetlands Adjacent to Upper Klamath and Agency Lakes, Oregon. Water-Resources Investigations Report 97-4059, Daniel T. Snyder and Jennifer L. Morace, investigators. U.S. Geological Survey, Portland. 1997. (predevelopment to development conditions)
United States Reclamation Service
1:250,000 scale compilation sheet of late 1880s mapping completed by the USGS and published by USGS and USRS in 1905 as Klamath Project, California – Oregon, General Progress Map, April 1905. (predevelopment conditions)
1:48,000 scale sheet (left-half) published by U.S. Reclamation Service in 1905 as Topographic and Irrigation Map, Upper and Lower Klamath Projects, California – Oregon, 1905. (predevelopment conditions)
Klamath Project, California – Oregon, General Report, September 1910. E. G. Hopson, Supervising Engineer; W. W. Patch, Project Engineer. United States Reclamation Service, Klamath Falls. (predevelopment to development conditions)
Bureau of Reclamation
Comprehensive Report on the Development of Water and Related Resources of the Upper Klamath Basin, March, 1954. E. L. Stephens, Project Manager. (Also known as the Upper Klamath River Basin [Report], Oregon – California.) (predevelopment to present-day conditions)
State of Oregon
Report of the Oregon Klamath River Commission, December, 1954. Lewis A. Stanley, Engineer. (predevelopment to present-day conditions)
Klamath River Inter-Tribal Fish and Water Commission and Humboldt State University, Arcata, California
Relationship between flows in the Klamath River and Lower Klamath Lake prior to 1910. Bertie J. Weddell. Proceedings, Klamath Basin Fish and Water Management Symposium (February 2002), Part 1: Geology, Hydrology and Water Quality in the Klamath Basin, pp. 1-43 to 1-55. (predevelopment to development conditions)
Oregon State University
Water Allocation in the Klamath Project, 2001: An Assessment of Natural Resource, Social, Economic, and Institutional Issues with a Focus on the Upper Klamath Basin. Oregon State University Special Report 1037, reprinted May 2003, 401 pp. (predevelopment to present- day conditions)

Estimation of crop water use and water used by wetland and riparian vegetation was necessary in portions of the basin. Net potential evapotranspiration (ET), which is potential ET minus effective precipitation (EP), was calculated by estimating these two components using proven methods. (The terms evapotranspiration (ET) and consumptive use (CU) are used interchangeably throughout this report.) The modified Blaney-Criddle method was used to determine potential ET from crops, marshlands, and riparian zones. Effective precipitation has been estimated by various methods. Details regarding the application of this methodology are given in attachment A. The methods are empirical and use crop coefficients derived for the specific crops and vegetation types evaluated. To estimate water used by irrigated lands by this method requires the following data:

- Location of irrigated lands
- Types of crops, number of acres and growing season for each crop type
- Diversion records, if available, and knowledge of water use practices
- Monthly precipitation and monthly average temperature for the area

Location of irrigated lands and acreages were taken from maps generated by OWRD. The types of crops evaluated were based on information reported by NRCS (2004) and by the California Polytechnic Universities Irrigation Training and Research Center (Freeman, 2005). Although diversion records were not generally available, water use practices were observed and diversions (specifically for the Modoc Canal) were estimated based on the water needed to meet an irrigation application efficiency assumed to be about 65 percent. Climatological data were acquired from information published by the National Oceanic and Atmospheric Administration (NOAA).

Data required using this method for marshlands and riparian areas are as follows:

- Location of marshlands and riparian areas
- Types of vegetation and existing and predevelopment acreages of each type within the marshlands and riparian areas
- Knowledge of seasonal factors, including growing season, which may affect marsh and riparian ET
- Monthly precipitation and monthly average temperature for the area

Annual water uses determined by the modified Blaney-Criddle method were adjusted based on other studies and to address water limiting considerations as described in attachments A and F, and were then integrated into a water budget for each specific area.

Methods to Estimate Natural Flows

For any chosen period of record, an assessment of natural streamflow must consider changes that occurred upstream. Some changes may have a minimal, or negligible, impact. Other changes may be accounted for, and depending on the methods used, the alterations to streamflow can be reasonably determined. Many changes, however, may have an impact that is very difficult to assess, or may affect the timing and alter the volume of streamflow in such a way that the alterations noted have little overall effect. In this study, the accounting of natural inflow and natural losses has been evaluated principally by employing data adjustment and correlation techniques. The resulting time series of monthly estimated natural flows was developed for the 52 years from 1949 to 2000. In addition to the inflows to Upper Klamath Lake, the results of the water budget assessment include natural flow estimates for two important stream gages, one located on the Link River at Klamath Falls and the other on the Klamath River at Keno.

Natural Streamflow Development

The methods used in this study were specific to subbasin areas as described in attachment B. For some areas, an adjustment of gaged streamflow to natural flow was required. Other areas required restoration of missing streamflow and climate data. Ungaged watersheds required an estimate of natural flow based on nearby gaged watershed. Groundwater contributions were assessed using a regional, climate-based approach, and transit losses were evaluated for some areas, as well.

Adjustment of Gaged Streamflow to Natural Flow

Areas with irrigated agriculture require adjustment of gage records to reflect the effects of crop water use. Gage records, which reflect crop net consumptive use, may be adjusted to natural flow using crop and marshland net evapotranspiration (ET):

natural flow = gaged flow + crop net CU – reclaimed natural marshland net ET

Irrigation return flows that are delayed in returning to the stream must also be considered. The net impact to the gage is from the net ET incurred by the irrigated crops because this is the amount of diverted and applied water that is lost and not appearing at the gage. Once net ET is determined, the resulting natural flow becomes part of the inflow to Upper Klamath Lake.

Restoration of Missing Climate and Streamflow Data

Correlation analysis was used to restore missing values from monthly-value data records used in this study. Restoration means filling in of missing records and/or extension of short records for climatological or streamflow stations. Details regarding the calculations and the method are given in attachment C. This process is a common and accepted practice.

Meteorological records for precipitation were recovered from digital media, and missing values were researched by reviewing the published records on microfiche. Other researched meteorological records were retrieved from published data summaries that cover an available period of record for southern Oregon from approximately 1865 to 2003. Temperature records were recovered from digital media and generally were not researched. Meteorological records were extended to restore missing values.

All primary records were restored for missing values covering the recorded period for which data were available and were extended, as necessary, to bracket the period of interest from before 1947, if possible, to about 2002. The recovery and extension of data were accomplished using correlation analysis. This task was accomplished using both supportive and primary records. However, not all records embrace the nearly 145-year period from 1865 to 2003. Meteorological records before about 1900 are difficult to recover as complete histories because of missing values. Commonly, equipment would break or fail, and 1 or 2 years would pass before replacement parts were available and delivered for the repair and re-installation. Because equipment was scarce, it was occasionally moved to a new location, thereby ending the continuity of the records acquired at the previous location (Table 2). Some of the meteorological stations used in this study (Table 2) near Upper and Lower Klamath Lake are depicted in Figure 5.

Table 2. Meteorological records used in the assessment

Location	Researched yes or no	Primary or Supportive / basis	Climate year period of record	
			Published	Extended/Restored
Butte Falls 1 SE	Yes-p	Supportive	1909-22, 1940-1986	
Chemult	Yes-p	Primary	1937-2001	1937-2001
Chiloquin, Chiloquin 1 E	Yes	Primary	1913-1979	1948-2001
Chiloquin 7 NW	Yes	Primary	1980-2001	1948-2001
Crater Lake National Park HQ	Yes	Primary/basis	1930-2001	1932-2001
Fort Klamath 7 SW	Yes	Primary	1953-1965	1947-2001
Fremont 5 NW	No	Supportive	1918-1996	
Gerber Dam	Yes	Supportive	1925-2003	
Keno	Yes	Supportive	1927-2001	
Klamath Falls 2 SSW	Yes	Primary/ supportive	1894-2001	1908-2001
Klamath Falls Ag. Exp. Sta.	Yes-p	Supportive	1942-1988, 1996-2002	
Lakeview 2 NNW	Yes	Supportive	1910-2001	
Lava Beds National Monument	Yes	Supportive	1959-2001	
Lemolo Lake 2 NNW	No	Supportive	1978-1997	
Malin 5 E	No	Supportive	1969-2001	
Merrill 2 NW	No	Primary	1949-1968	1929-2000
Paisly	Yes	Supportive	1925-2001	
Prospect 2 SW	Yes	Supportive/basis	1931-2001/c	
Rocky Pt. 3 S	Yes	Primary	1966-1975	1947-2001
Round Grove	Yes	Primary	1920-1987	1920-2001
Sprague River 2 SE, 1E	Yes	Primary	1953-2001	1921-2001
Tule Lake	Yes	Supportive	1932-2001	
Yonna	Yes	Supportive	1907-1948	

Note: -p = partially, /basis = basis station, /c = complete

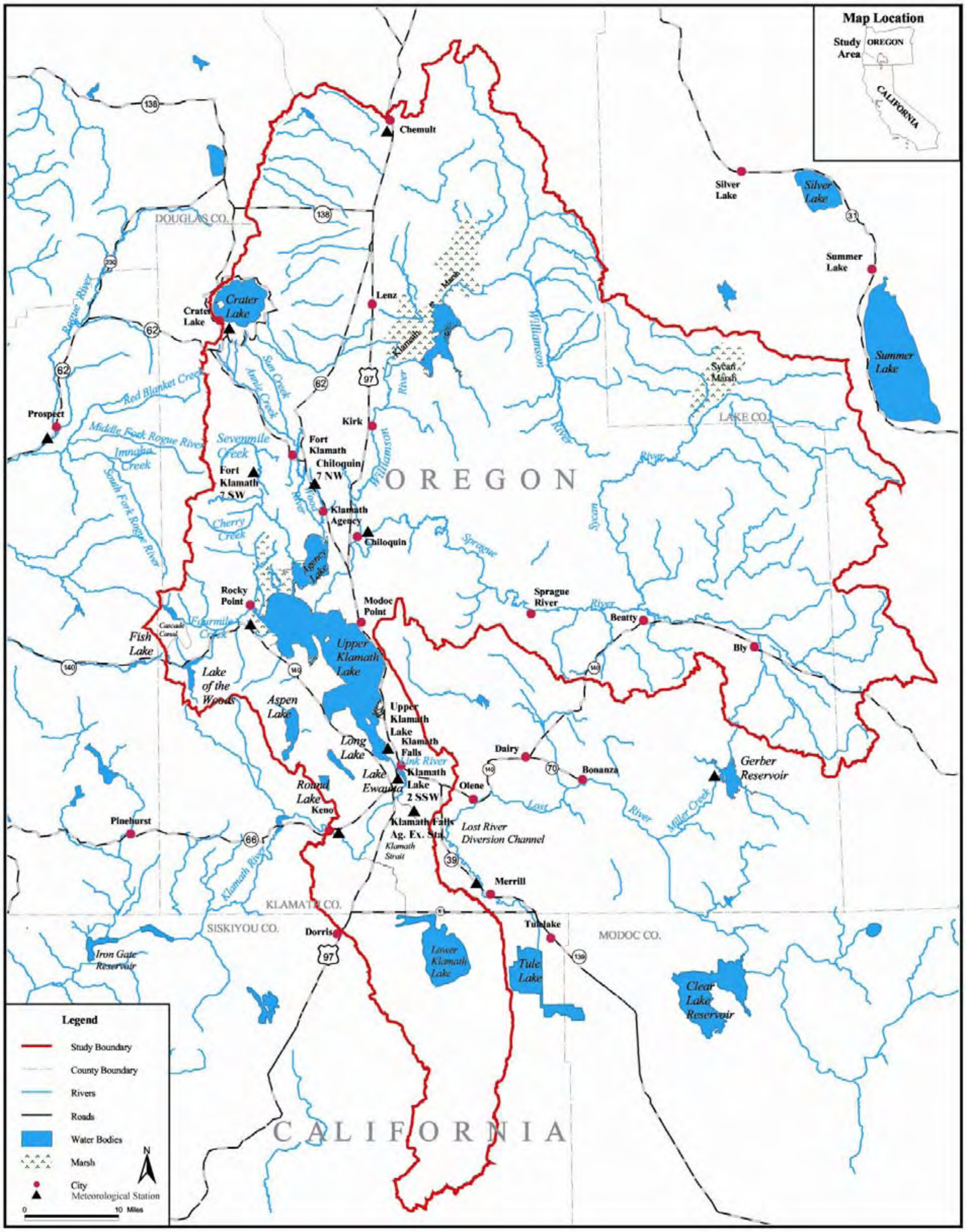

Figure 5. Approximate location of some meteorological stations near Upper and Lower Klamath Lakes are depicted as triangles.

Data records used in developing this empirical assessment include hydrologic records of streamflow and lake stage, in addition to precipitation and average temperature histories. Stream gaging did not begin until about 1905 in the Upper Klamath Basin. In many cases, stream gaging was fraught with difficulty because of equipment malfunction and failure or high maintenance and field calibration costs. Some gaging data collection was for individual studies or, in the priority of needs and uses, equipment was moved and new records obtained from a different location. For these reasons, many records, whether meteorological or stream gaging, are incomplete. Gaged discharges from watersheds already in natural condition, but having minimal gaging histories, were extended to cover the period of interest. A generally complete listing of data records is provided for stream gages in Table 3. The locations of those gages are shown in Figure 6.

Table 3. Stream gaging station records used in the assessment

Gage number and location	Primary or supportive/ basis	Water year period of record: Published/recovered	Extended/ restored
11491400 Williamson River below Sheep Creek	supportive	1979-1992	
11493500 Williamson River near Klamath Agency	supportive	1955-2000	
11494000 Williamson River above Spring Creek near Klamath Agency	supportive	1912-1926/sparse	
61420209 Sycan River above Sycan Marsh	supportive-p(FS)	1992-2000	
11497500 Sprague River near Beatty	supportive	1954-1992	
11499000 Sycan River near Beatty	Supportive	1917-1925	
11499100 Sycan River below Snake Creek near Beatty	supportive	1973-2002	
11501000 Sprague River near Chiloquin	primary	1921-2000	
11502500 Williamson River below Sprague River near Chiloquin	primary	1918-2002	
11503000 Annie Spring near Crater Lake	supportive	1977-2002	
11503001 Combined flow Annie Spring + diversion	supportive	1977-1982	
61420301 Annie Creek near Crater Lake	supportive-p(FS)	1992-2002	
11503500 Anna Creek near Fort Klamath	supportive	1922-1928/sparse	
11504000 Wood River at Fort Klamath	supportive	1913-1937	
11504100 Wood River near Fort Klamath	supportive	1964-1968	
61430399 Wood River at 11504000 near Fort Klamath	supportive	1994-1998/sparse	
11504200 Crooked River near Fort Klamath	supportive	1964-1967	
364 Fourmile Lake Reservoir near Recreation	supportive	1937-1978, 1985, 1992-2002	
11504600 Cascade Canal at Fourmile Lake near Lake Creek	supportive	1922-1979, 1991-2002	
11505500 Fourmile Creek near Odessa	supportive	1912-1918/sparse	
11505600 Fourmile Creek near Rocky Point	primary	1964-1967	
11505700 Varney Creek near Rocky Point	primary	1964-1967	
61420303 Sevenmile Creek near Fort Klamath	primary-p(FS)	1992-2002	1947-2002
61420302 Cherry Creek near Klamath Agency	primary	1992-2002	1947-2003
11507000 Upper Klamath Lake, stage	primary, supportive	1904-1905,1905-1918	
11507505 Link River total flow at Klamath Falls	primary, supportive	1904-1919	
11509500 Klamath River at Keno	primary, supportive	1904-1914	
LKL Lower Klamath Lake near Brownell, stage	primary, supportive	1904-1914	
GER Gerber Reservoir stage, outflow	supportive	1926-2001	
61420101 Cottonwood Creek near Beaver Marsh	supportive-p(FS)	1992-2000	
61420102 Miller Creek near Beaver Marsh	supportive-p(FS)	1993-2000	
61420103 Sand Creek near Lenz	supportive-p(FS)	1992-2002	
61420104 Sink Creek near Lenz	supportive-p(FS)	1995-2000	
14060800 Big Marsh Creek above Collins Ranch near Crescent	supportive	1924-1929/sparse	
14061000 Big Marsh Creek at Hoey Ranch near Crescent	supportive-c	1912-1914, 1924, (1924-1928), 1928-59	1912-2000
14145500 Middle Fork Willamette River above Salt Creek near Oakridge	supportive	1935-1962	
14147500 North Fork of Middle Fork Willamette River near Oakridge	supportive	1909-1916, 1935-1995	
14308000 South Umpqua River near Tiller	supportive/basis	1911-1912, 1940-2002	
14327500 Rogue River above Bybee Creek	primary, supportive	1930-1952	1930-2000
14328000 Rogue River above Prospect	primary/basis	1908-1912, 1924-1999	1914-2002
14330000 Rogue River below Prospect	primary	1914-2002	
14330500 South Fork Rogue above Imnaha Creek near Prospect	primary	1931-1950	
14331000 Imnaha Creek near Prospect	primary, supportive	1934-1949	1934-2000
14332001 South Fork Rogue + South Fork Power Canal near Prospect	supportive	1924-1984	1924-2000
14333000 Middle Fork Rogue River near Prospect	primary	1925-1955	1925-2000
14333500 Red Blanket Creek near Prospect	primary, supportive	1925-1982	1925-2000

Notes: -p = provisional (source); -c = combined; /basis = basis station; FS = Forest Service in U.S. Department of Agriculture

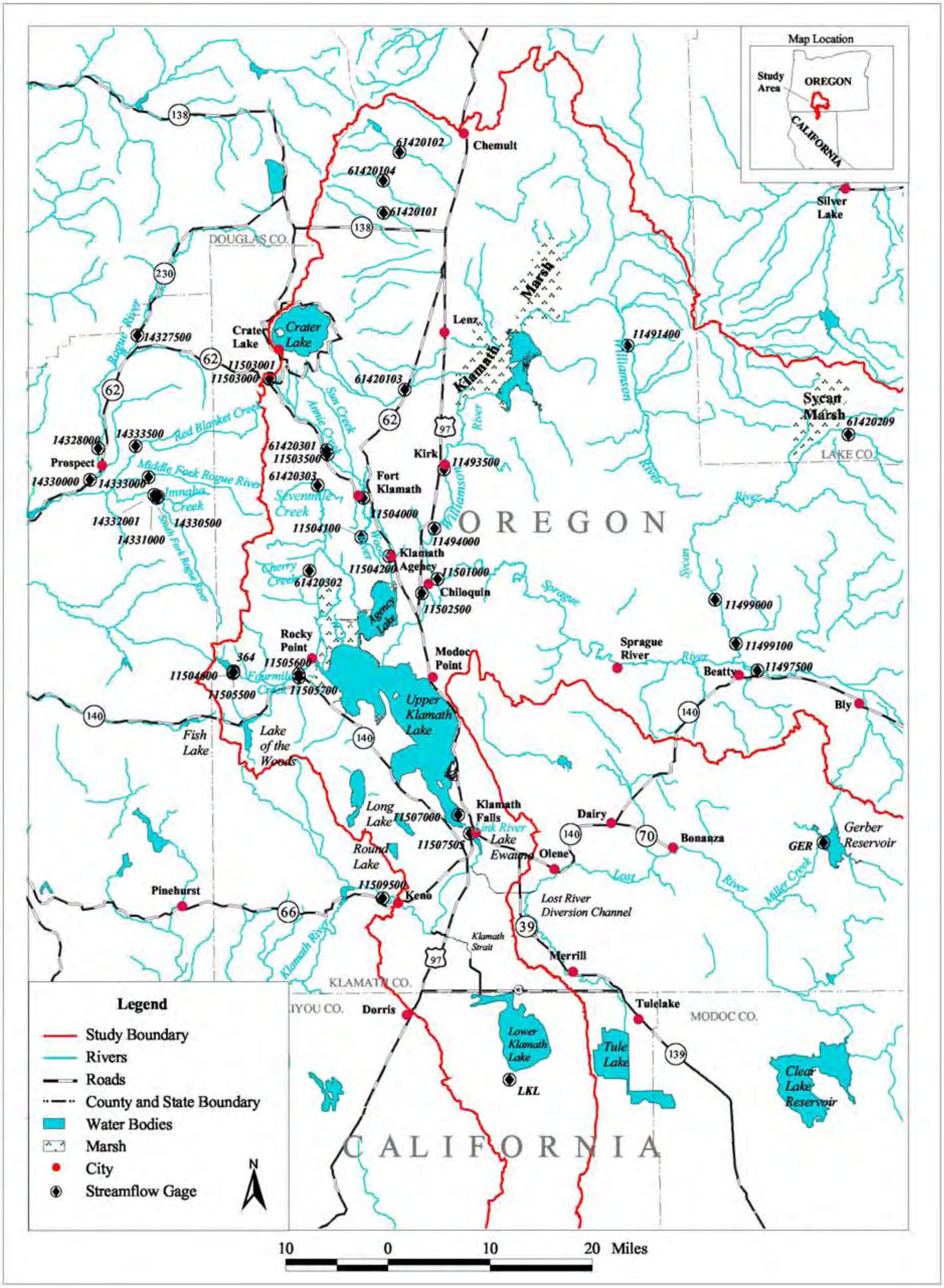

Figure 6. Streamflow gages used in this study.

Natural Streamflow Estimates in Ungaged Watersheds

Natural flow histories are required in the ungaged watersheds to assess the natural inflow to Upper Klamath Lake. Monthly flow records are sparse for streams heading on the east flank of the Cascades and flowing into the Wood River Valley or Pelican Bay area of Upper Klamath Lake. Details regarding the data methods that were used are given in attachments B and C. Although many of these streams have had miscellaneous (or incidental) flow measurements made from time to time, there are no continuous streamflow records for these streams for the period of interest. Some of these streams have been gaged from as little as less than 3 to, in some cases, more than 12 years. Therefore, estimation of the needed portion of these flow records was completed as follows:

1. Obtain all available gaged data, including any miscellaneous, instantaneous streamflow measurements.

2. Determine how natural these data are. If necessary, remove diversion effects.

3. Determine similarities between the Rogue River watershed - Wood River Valley tributaries and gaged streams nearby based on geology, hydrograph shape or prominent flow regime, and baseflow characteristics.

4. Develop total monthly flows for gaged periods by relating instantaneous flow measurements to at least two other concurrent daily gaged records.

5. Relate monthly total discharges to those that are concurrent from a nearby, similar gage with longer period of record.

6. Create a synthetic natural time series based on monthly total flow correlation equations.

For watersheds exhibiting different geologic or flow regime conditions, specific natural flow assessments based on specially adapted techniques were used. For example, temperature and precipitation data were not used in the standard process; however, these data were integral in estimation techniques employed for the Annie Creek and Denny Creek watersheds.

Similarly, the need to temporally adjust headwater spring-discharge accruals to the Wood River, tributary inflow to the Wood River from Fort Creek, and inflow to Upper Klamath Lake from Crooked Creek was met by evaluating the climate signal, discussed fully in chapter 2, evident in longer-term records for similar groundwater discharges in neighboring watersheds.

Natural incidental recharge in the Wood River Valley and drainage of this groundwater to streams that form hydraulic boundaries to Upper Klamath Lake have been included in this study and addressed later in this report. Drainage of natural recharge to the Wood River and Sevenmile Creek would provide additional inflow to Upper Klamath Lake.

Transit Losses

Transit losses are conveyance losses. When water flows from one area to another area for either delivery for agricultural use or just flowing downstream, some of that water is lost in the process to evaporation, ET, and aquifer recharge. The water can be lost to the system (consumptive use) or returned to surface or groundwater bodies (return flow). In some areas, conveyance or transit losses can amount to 20 percent of the flow.

Natural Lake Simulations

Implementation of a water budget for Upper Klamath Lake required developing information about (1) the storage and inundation surface area characteristics of the lake, and (2) the discharge characteristics at the outflow point of the lake. These characteristics were evaluated in relation to the stage of the water surface of the lake. Lake stage is given as the gage height reading of the water surface. Additionally, discharge from the lake was also related to the stage.

Estimating the outflow of a natural lake is accomplished using a monthly water budget approach by using the general form of the hydrologic (mass balance) equation; namely,

$$i = o + \Delta s$$

where

i = inflow to lake
o = outflow from lake

and

Δs = change in storage of lake

Therefore, with definition of the needed characteristics, the hydraulic performance of the lake could be simulated in a month-to-month water budget that accounted for natural inflow, storage of water within the lake, resulting estimated lake stage, and discharge from the lake. In addition, groundwater discharge to the lake from the regional aquifer was noted. The water budget assessment was designed to simulate the lake as a natural water body.

Groundwater Contributions

Significant unmeasured groundwater inflow for Upper Klamath Lake was described in a USGS report by Hubbard (1970). A careful re-evaluation of Hubbard’s work, assisted by file materials provided by the USGS WRD Oregon District Office, allowed inclusion of these data in this study. These data were also adjusted by use of a climate signal approach discussed in chapter 2.

Open Water Surface Evaporation

The Hargreaves equation, adjusted to correlate closely to limited period Kimberly-Penman evaporation numbers, was used to calculate the estimated evaporation incurred by lake open water surface areas. The estimation is based solely on air temperature and latitude of the meteorological station being evaluated. These data are generally available whereas pan evaporation data at various stations are not generally available (see attachment D). The resulting calculated monthly evaporation is applied to specific open water surface areas to determine monthly lake evaporation. Data requirements for use of the equation are as follows:

1. Daily maximum and minimum air temperature data, if available, or an estimate of these data from monthly values if daily values are unavailable.

2. Latitude of the site for which evaporation is to be estimated.

3. Monthly precipitation for the evaluated site.

4. Open water surface area for which evaporation is to be estimated.

Assumptions

The assessment of natural inflow to Upper Klamath Lake and the simulation of the natural lakes included the following additional key assumptions and criteria.

1. The climatic regime of the time period for which streamflow records were naturalized is not significantly different than that of the predevelopment period.

2. The correlation analysis and statistical reconstruction of missing meteorologic and hydrologic data is assumed to be adequate and reasonable of the timing and variability estimated to exist for such records.

3. Interpretive assessment of Upper Klamath Lake, based on detailed published maps of the existing pre-twentieth century landscape, is assumed to adequately represent average predevelopment conditions of the lake. The estimated predevelopment riparian marsh conditions along the river and creek corridors, based on interpretation of modern aerial photography, are assumed to represent average conditions.

4. Difficulties encountered before 1919 with the operation of the Friez recorder on Upper Klamath Lake are assumed to be adequately understood in developing the rating curve used for outflow from the lake.

5. The discharge-rating curve developed for the simulation of Upper Klamath Lake is assumed to represent the hydraulically driven outflow processes.

6. As the relevant land-use changes significantly affecting flows are assumed to be reasonably close to the associated streams or lakes, the application of scientifically based theory and hydrologic method is assumed to be adequate to the analysis of the natural flows.

Chapter 2 — Natural Streamflow Development

This chapter describes how the monthly natural streamflow or the natural lake conditions were developed. The area of consideration, the changes from predevelopment conditions, the available information and the assumptions used in the analysis, the methods used to estimate natural conditions, and the results are provided in this section. Each river basin is discussed before moving to another basin.

In addition to agricultural developments, other changes in the watershed include clear-cutting in timbered areas, land clearing for pasture and ranching, suppression of fire in forested areas, and the consequent invasion of juniper into clearings and in areas adjacent to forest land that were not previously known to have juniper. Extirpation of beaver, channeling and diking streamcourses for flood control and land reclamation, and roadway encroachments have consequently reduced detention of streamflow and changed the character of stream baseflow from that incurred under natural conditions. The extents of these changes are very difficult to assess on a month-to-month basis and are beyond the scope of this study. Nevertheless, these changes are addressed at a watershed-level summary in chapter 3.

Upper Klamath Lake Basin

The Upper Klamath Lake Basin includes the Williamson and Wood River watersheds and Upper Klamath Lake and its marshland. The Sprague River is tributary to the Williamson River.

The present-day watershed contributing to Upper Klamath Lake has been fundamentally changed from that existing under predevelopment conditions. Among the most extensive changes has been the irrigation development, grazing, and diking and draining of marshlands around the perimeter of Upper Klamath Lake.

Williamson River Watershed

Total area of the Williamson River watershed is about 3,050 square miles. Before agricultural development, the Williamson River valley most likely appeared as a grassland prairie with groundwater seeps and wetlands scattered along the streams. Streams had attendant riparian marshes that supported sedges and rushes. These riparian areas probably had within them stands of birch, alder, willow, ash, dogwood, and elderberry, all of which are water-loving trees or shrubs.

Development of irrigated land and other similar changes have occurred along the streamcourse of the Williamson River. The primary crops include alfalfa and hay grass. Water is diverted from the Sprague River just above its confluence with the Williamson River to irrigate land on the Williamson delta adjacent to Upper Klamath Lake in the Modoc Irrigation District. Upstream along the Williamson River, to which the Sprague is a tributary, few changes occurred in the stream reach below Klamath Marsh. Although some of the wetlands of Klamath Marsh have been drained and reclaimed, much of the irrigation in the upper Williamson River watershed takes place above Klamath Marsh.

Within the Williamson River watershed, numerous wells pump from the confined regional aquifer. Assessment of the effect of this pumping on streamflow and inflow to Upper Klamath Lake was not assessed in this study.

Gaging Records

The present-day discharges of streams within the Williamson River basin are measured by long-term gaging stations with records that predate the period of interest. The Williamson River and Sprague River gages are near the confluence of these two major streams, near the town of Chiloquin, Oregon. Given the completeness in these gaging records, an assessment of watershed areas or an evaluation of discharges for individual subwatersheds was not critical to estimating the natural flows. The evaluation, therefore, was limited to completing an assessment of factors that would have significantly altered natural streamflow at the Williamson and Sprague River gages near Chiloquin.

Net Consumptive Use Determination

The watershed of the Williamson River captures and provides a large part of the natural inflow to Upper Klamath Lake. Estimating natural flow from the gaged flow of the Williamson River required an assessment of lands irrigated by diversions of streamflow and of reclaimed natural marshlands. Net consumptive uses on irrigated lands have depleted streamflow; these depletions were estimated and added back to gaged flow. Consumptive uses that would have been incurred by reclaimed natural marshlands would have caused a loss in natural flow, these losses were estimated and were subtracted from the summation of gaged flow and crop net CU. The resulting water budget for natural flow at the Williamson River gage near Chiloquin is straightforward:

natural flow = gaged flow + crop net consumptive use – reclaimed natural marshland net evapotranspiration

The accuracy of this water budget is affected by irrigation return flows that are delayed in returning to the stream. The Williamson River does not have well developed and transmissive valley-fill alluvial aquifers, and most of the irrigation diversions from the stream irrigate land that is near the stream. As such, these return flows are assumed to be not delayed significantly in returning to the stream after the application of diverted water to the irrigated field. This water, therefore, is already reasonably accounted for at the gage. Therefore, the net impact to the gage is from the net consumptive use incurred by the crops being irrigated as this is the amount of water lost and not appearing at the gage.

Crop net consumptive use may be defined as potential crop evapotranspiration less effective precipitation as described in attachment A. Meteorological data from nearby weather stations were used in supporting the calculations, and included monthly precipitation and monthly average temperature for the period 1947 through 2002. Although many meteorological records were fairly complete, nearly every record required some reconstruction or estimation of missing values to gain a complete time series for the selected period of analysis.

Evaluation of depletions to the Williamson River by diversions of the Modoc Canal was completed by using restored meteorological data for Chiloquin and irrigated acreage estimates to compute net ET for the Modoc Irrigation District. This depletion is applied to the Williamson gage near Chiloquin and is attributable solely to the diversion taken by the Modoc Canal from the Sprague River for use on irrigated lands below the Williamson gage. The Williamson River was restored to its present-day flow above the Sprague without the effect of this depletion by adding the estimated diversions for the Modoc back to the gaged flow history for the Williamson near Chiloquin, and subtracting the present-day gaged inflow from the Sprague.

Upper Williamson River Watershed

The upper Williamson River watershed (see Figure 7, including irrigated lands) includes the portion of the basin upstream of the Sprague River confluence, including Klamath Marsh. Total area is 1,392 square miles.

Changes from Predevelopment Conditions

Under natural conditions, spring-season inflow to Klamath Marsh was assumed to be stored, in part, within the marsh as a natural lake. Outflow from this lake to the Williamson would occur during the maximum inflow period in the early summer, while marshland evapotranspiration would deplete storage in the mid summer. The depletions are offset by snowmelt runoff and seasonal groundwater accruals to the marsh. Discharge from the marsh to the Williamson River during early to mid-summer under natural conditions was dependent upon snowfall conditions. As the marsh becomes senescent during the late summer, these depletions decline. Beginning in the late summer and continuing into the fall, declining inflow from groundwater slowly fills depleted storage within the marsh and discharge to the Williamson gradually resumes.

Natural Streamflow of Upper Williamson River

Evaluation of Klamath Marsh in its natural state would require much the same approach as has been completed for Upper Klamath Lake. A conceptual definition of the marsh would have to be developed that accounted for

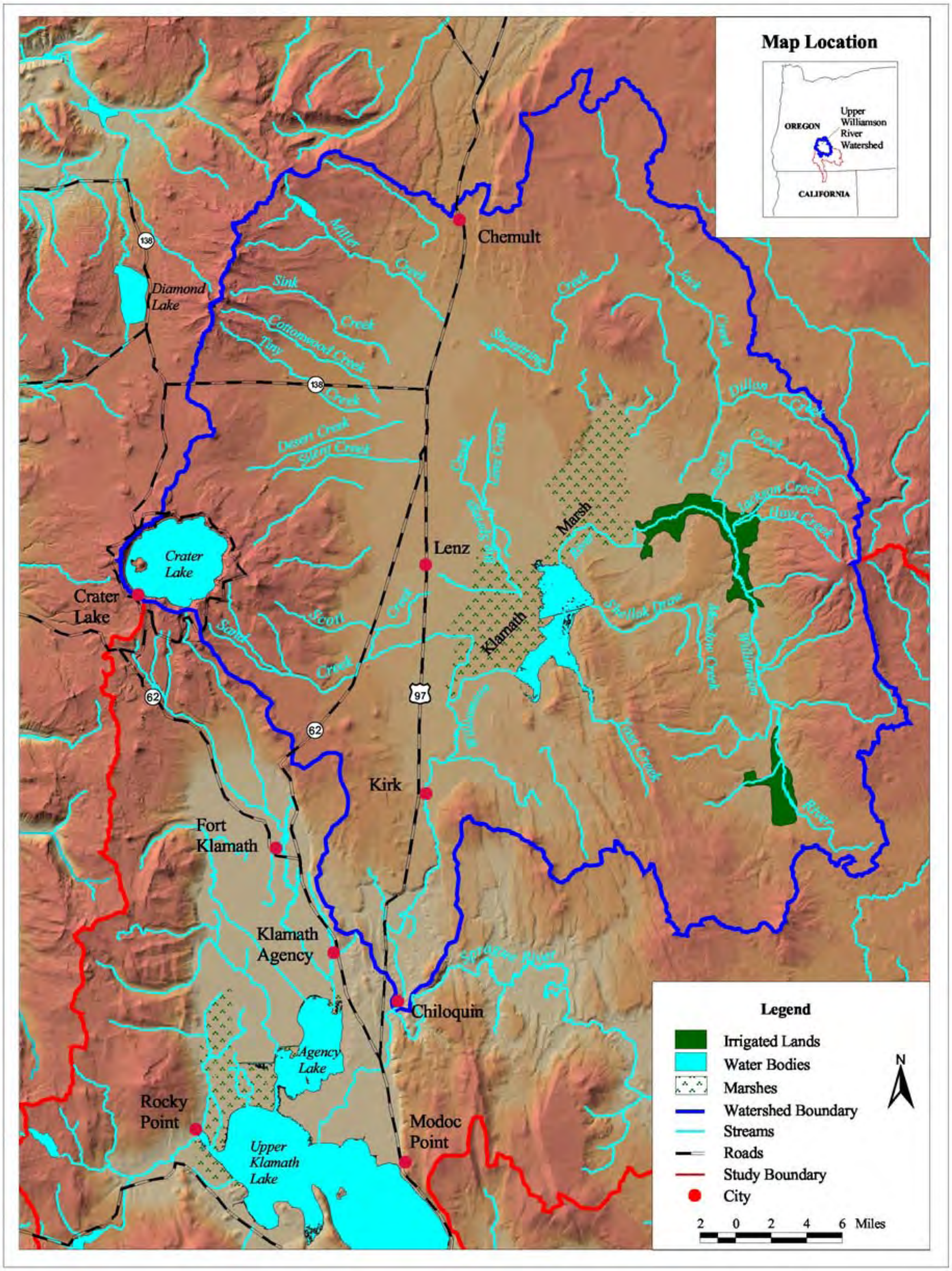

Figure 7. Extent of upper Williamson River watershed.

the dynamic interactions of natural inflow, storage, marshland evapotranspiration, and resulting outflow. A review of additional information that was provided (J. La Marche, hydrologist, OWRD, pers. comm.) for developing this assessment indicates that under natural conditions, little, if any, water from the Upper Williamson above the marsh probably was realized as significant flow in the Upper Williamson below the marsh during the summer months. A double-mass plot of accumulated annual flow of the Williamson River vs. accumulated annual precipitation at Crater Lake indicates no significant historical shifts in the relationship. Thus, an apparently reasonable assumption is that agricultural CU in the Williamson watershed has offset Klamath Marsh ET. Winter flows in the Williamson are generally unaffected by the marsh and are realized in the Lower Williamson at Upper Klamath Lake.

By adding back the irrigation net consumptive uses, and subtracting the reclaimed marsh net evapotranspiration, the water budget for the Upper Williamson would incorrectly handle the effect of irrigation upstream of the marsh and the effect of reclaimed marsh during the summer season. The resulting flow for natural conditions would not have been much different than indicated *without* the adjustments for the effect of the irrigation and reclaimed marsh. Therefore, these adjustments were not considered in the calculation of results. (See attachment B for a discussion of these adjustments.) The extent of the natural and current Klamath Marsh is shown in Figure 8. Thus, the restored present-day flow for the Williamson above the Sprague was used to determine natural flow for the Williamson.

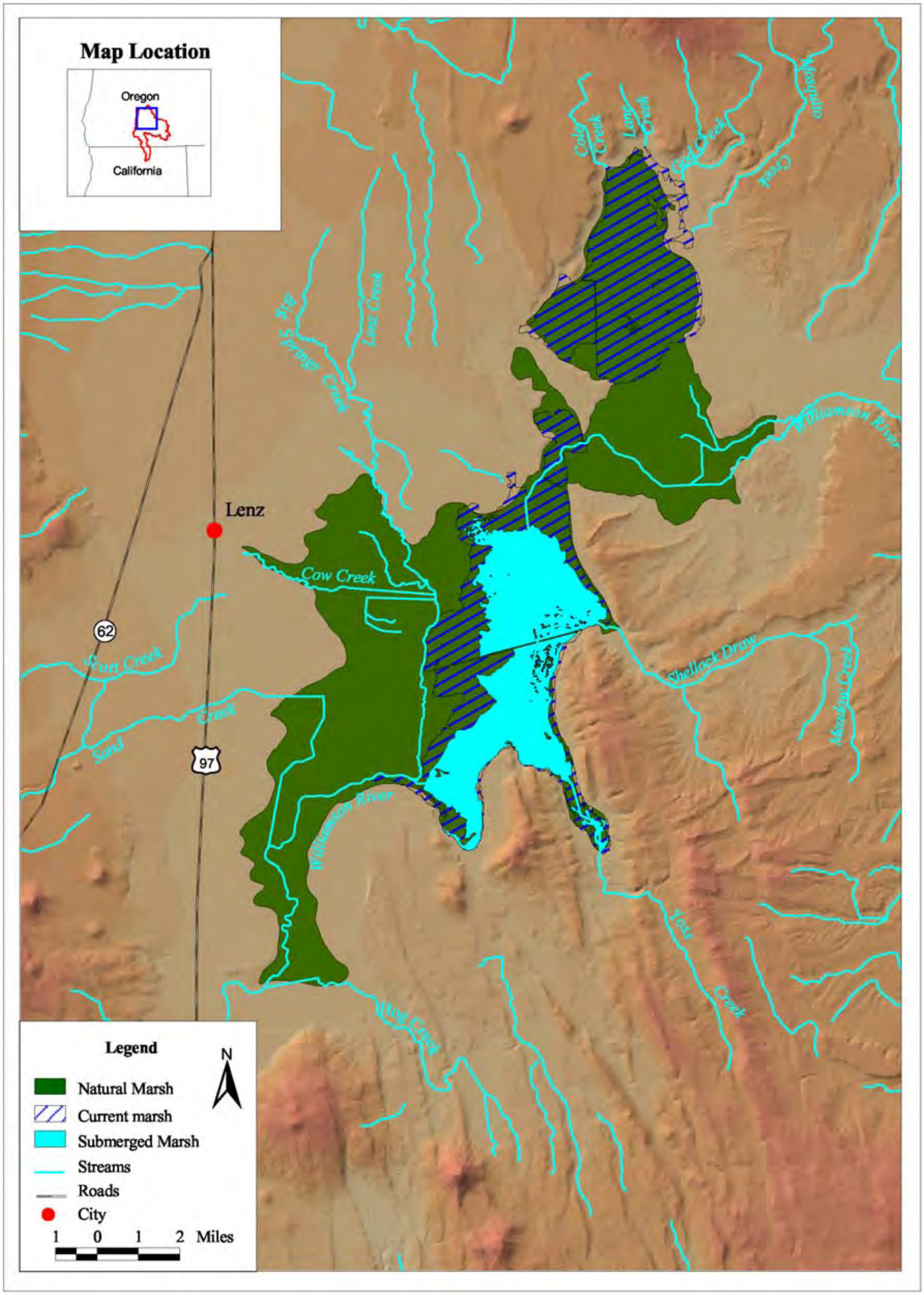

Figure 8. Extent of natural and current Klamath Marsh.

Sprague River Watershed

The Sprague River watershed extends eastward from the river's confluence with the Williamson River. Total area is 1,610 square miles. Figure 9 shows the extent of the Sprague River watershed, including the irrigated lands.

Changes from Predevelopment Conditions

The most significant changes affecting natural flow of the Sprague River relate to the development of irrigated croplands and the reclamation of marshlands for irrigation. Figure 10 shows the affected and non-affected marshlands of the Sprague River watershed.

The changes in Sycan Marsh from its natural condition are difficult to assess because information regarding irrigation developments in Sycan Marsh is unavailable. Ongoing water-rights proceedings and other data limitations are factors in this assessment. The net ET rates from the natural-marsh vegetation that existed before development were likely similar to or slightly higher than net ET rates of the vegetation that exist under managed condition (L. Bach, pers. comm.). If the total area of natural marsh was greater than current irrigated area, outflow from the marsh may have been less than at present. For this study, natural conditions and current conditions were assumed to be identical in terms of consumptive use of water in the Sycan Marsh area.

Natural Streamflow of Sprague River Watershed

Evaluation of net consumptive uses for irrigated lands and for reclaimed natural marshlands was based on meteorological data collected at several sites. Incomplete records for the Round Grove station and for the Sprague River station were restored by correlation with other nearby stations. For the Sprague River above Beatty, consumptive uses were determined for irrigated pastureland and marshlands based on meteorological data for the Round Grove station.

Below Beatty, consumptive uses were determined similarly using meteorological data for the Sprague River station. The total of these net consumptive uses for irrigated pastureland was added to the flow record for the Sprague River near Chiloquin. Similarly, because reclaimed natural marshland would have depleted the flow of the Sprague River under natural conditions, the loss determined by the net consumptive use of the reclaimed marsh in each respective area was subtracted, in total, from the resulting flows determined for the Sprague River gage.

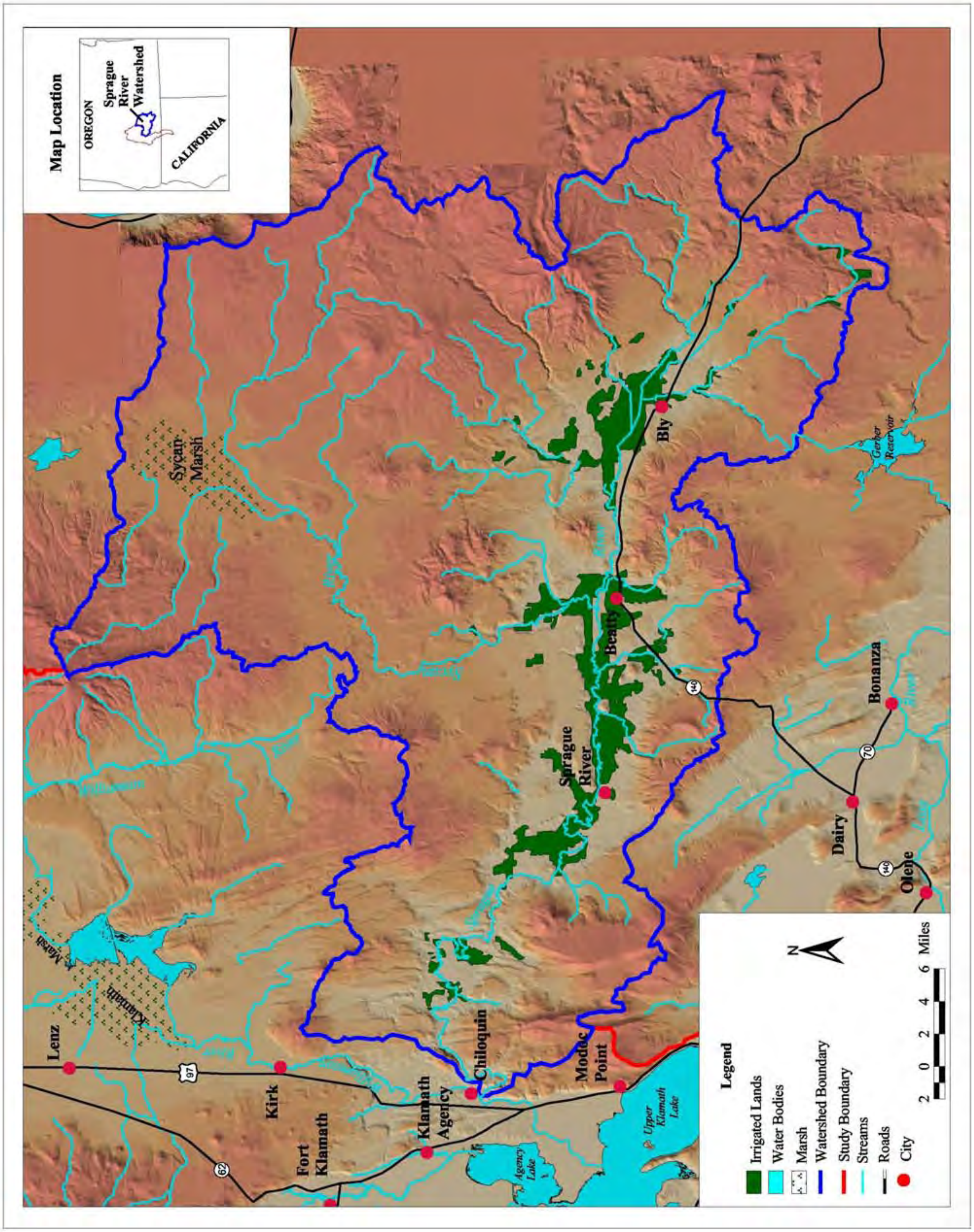

Figure 9. Extent of Sprague River watershed.

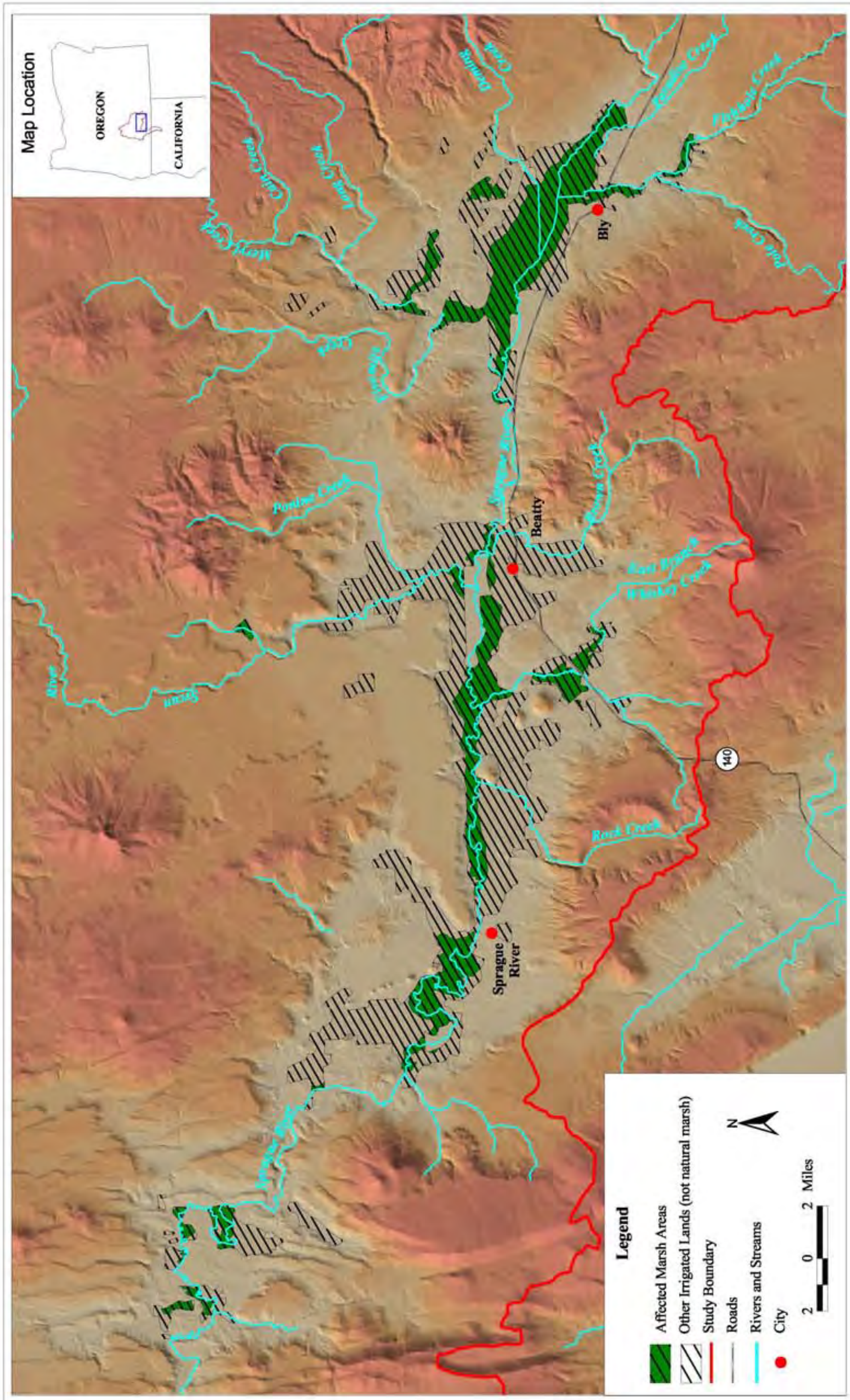

Figure 10. Affected marshlands of the Sprague River watershed.

Assessment of irrigated lands in the Sprague River basin was based on information provided by the State of Oregon Water Resources Department. Affected natural marshland areas were assessed through photo-interpretation of ortho-rectified color aerial photography provided to the Klamath Basin Area Office by the Fish and Wildlife Service. Detailed evaluation of these areas was posted on 1:63 360 scale 15 minute quadrangles which were overlaid for each coverage type to determine the affected natural marshland area for the natural loss assessment. Affected and nonaffected marshlands were also mapped based on indications shown on the 15 minute quadrangles. The areas of affected marshlands were planimetered, and the total marshland areas were calculated (attachment A).

Watershed conditions were also evaluated using a mosaic-composite of individual 15 minute digital ortho-photo quadrangles reproduced at a scale of 1:63 360. Four adjacent 7.5 minute ortho-photo quadrangle frames were used in developing each of these 15 minute ortho-photo quadrangles. The individual frame images are available from the USGS, and spanned two image acquisition dates. The composite ortho-photo image for each 15 minute quadrangle at its respective imaging date was examined for evident changes in watershed conditions. From the first image in 1994 to the last in 2000, generally noticed changes in watershed conditions were related to re-growth of logged areas. Most clear-cutting was noted as non-extensive and appearing as random, smaller cut areas, which would indicate this activity has had minimal impact to hydrologic response of the watershed.

Lower Williamson River Watershed

The lower Williamson River watershed is the short stretch of Williamson River from the confluence with the Sprague River to Upper Klamath Lake. The combined Williamson and Sprague Rivers flow to Upper Klamath Lake through this stretch of river. Transit losses through this area are estimated to be minimal in this reach, thus the combination of Upper Williamson River and Sprague River natural flows comprise the total estimate of natural flow from the Williamson River watershed. The lower Williamson River watershed is shown in Figure 11.

Results in the Williamson River Watershed

Natural inflow to Upper Klamath Lake from the Williamson River was determined as the sum of the restored natural flow of the Sprague above its confluence with the Williamson, and restored natural flow of the Williamson above the Sprague. The combined inflow of these streams was determined as an annual average of about 878,000 acre-feet for the 52-year period of interest being considered.

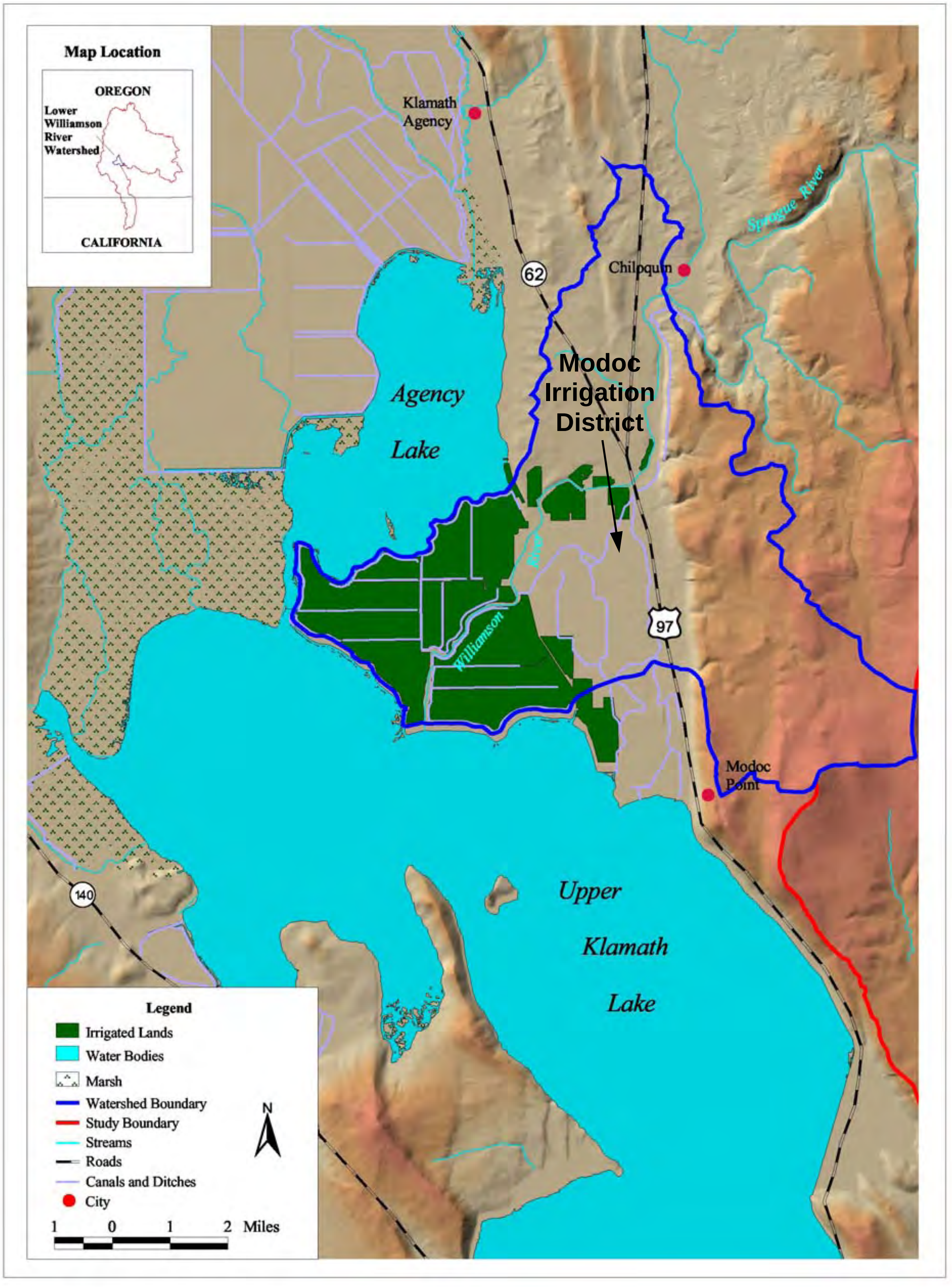

Figure 11. Extent of lower Williamson River watershed.

Wood River Valley and East Cascade Area

The Wood River Valley and East Cascade area, as defined herein, extends from Crater Lake in the north to Round Lake in the south, and the Cascade Range in the west. Figure 12 illustrates the extent of the Wood River Valley, which includes Upper Klamath Lake and Agency Lake. Numerous streams drain off the eastern flank of the Cascade Range in the Wood River Valley, including Sevenmile Creek, Cherry Creek, and Fourmile Creek. Annie Creek and Sun Creek flow south off the southern flank of the ancient volcano of Mount Mazama in the north. Streams and aquifers in the Wood River Valley receive baseflow contributions from this area. Many groundwater seeps and springs are located along the valley, with the largest (Wood River Springs) located on the northeastern side of the valley floor. The Wood River Springs provides substantial flow to the Wood River, which flows directly into Agency Lake.

Although Upper Klamath Lake is located within this tributary basin, it will be discussed in the following section.

Changes from Predevelopment Conditions

Significant changes to landscape and vegetation have occurred in the lower elevations of the Wood River Valley as a result of agricultural development. Before development, these areas most likely appeared as a grassland prairie with groundwater seeps and wetlands scattered along the valley floor. A woodland crossed the northern end of the valley floor. Streams flowing eastward from the Cascades and southward from the flank of Mount Mazama, as well as from springs along the eastern valley wall, had attendant riparian marshes that supported sedges and rushes. These riparian areas probably had within them stands of birch, alder, willow, ash, dogwood, and elderberry, all of which are water-loving trees or shrubs.

Today, the lower elevation areas of the Wood River Valley have been extensively reclaimed for pasture. The riparian marshes and stands of trees are mostly gone, except for those noted along the margins of Crooked Creek and Fort Creek and near Wood River Springs. Streams flowing into the valley have been extensively re-channeled and diverted for flood irrigation of pasture. A network of drains collects end-field losses and groundwater from irrigation applications and percolation losses. This drainwater is successively distributed into ditches and laterals to again be used to irrigate additional pasture. Percolation losses from flood irrigation also recharge the basin-fill groundwater reservoir of the Wood River Valley and cause increased groundwater underflow into Upper Klamath Lake.

Even though the floor of the Wood River valley has been altered significantly, most of the contributing headwater areas have not been affected by agricultural development. The primary reason for this is due to land management activities in Crater Lake National Park and the Winema National Forest. Crater Lake National Park is located on the north end of the valley and protects the headwaters of Annie Creek and Sun Creek from timber removal or agricultural practices. Also,

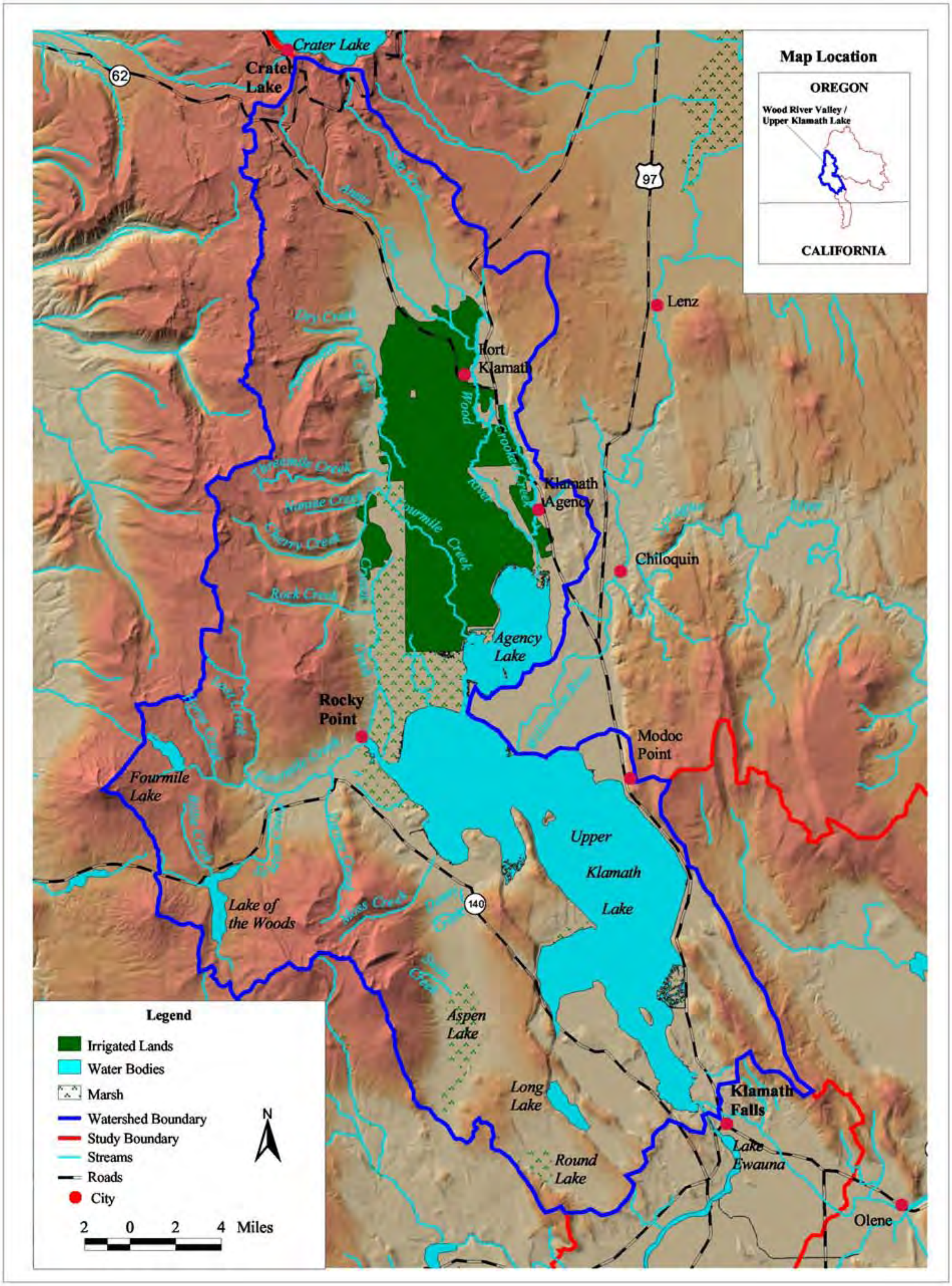

Figure 12. Extent of Wood River Valley and East Cascade area.

the Sky Lakes and Mountain Lakes Wilderness Areas of the Winema National Forest prohibit these same practices in the headwaters of creeks on the east flank of the Cascades (Sevenmile, Threemile, Nannie, Cherry, Rock, Fourmile, and Moss Creeks).

In the Wood River Valley, numerous wells penetrating the alluvial fill produce artesian groundwater. Such water is used for irrigation, some stock watering, and other uses. Many of these artesian wells are uncapped and may be observed to be freely flowing. The consequence of these wells on groundwater discharge to Upper Klamath Lake from the regional aquifer is difficult to assess and was not determined.

Natural Streamflow of Wood River Valley

Natural inflow to Upper Klamath Lake from the Wood River Valley was estimated by developing synthetic records for each tributary between October 1948 and September 2000. Several methods were employed to estimate natural streamflow depending on the availability of measured streamflow data, the location of diversions, basin characteristics, dominant flow regime (surface water or groundwater), and lack of data. The resulting time series for each watershed are explained in more detail in attachment C.

In general, several years of streamflow measurements are available for Wood River Valley streams, but very few streams have continuous periods of daily records beyond a few years. Most of the available data in the Wood River Valley are considered natural, because few agricultural diversions were located upstream of the gage. Where diversions were found, site-specific adaptations were made to develop a natural streamflow time series. If upstream diversions have been recorded or can be estimated, as in Fourmile Creek, gaged streamflow records were naturalized before being used further. When upstream diversions were extensive, other methods were used to estimate streamflow.

For example, the flow of the Wood River consists of surface water from Annie and Sun Creeks, as well as spring flow from the Wood River Springs. Several diversions occur just below Wood River Springs, and these diversions are rarely measured. For several years, streamflow and diversions were accurately measured in Wood River, so the natural streamflow has been documented for a short period of time. Fall River is a tributary to the Deschutes River and is also dominated by spring flows. A comparison of this natural streamflow in the Wood River illustrated a consistent relationship between natural Wood River streamflow and Fall River streamflow. This comparison allowed for a determination of long-term groundwater contributions in the Wood River based on the historic fluctuations that occurred in Fall River. Other streams dominated by spring releases were also determined in a similar fashion (Crooked Creek and Fort Creek).

In some cases, only instantaneous daily streamflow measurements were available instead of a continuous daily record. When sufficient concurrent measurements were available between a nearby gage and the ungaged watershed (i.e., at least one measurement per month for several months), monthly total flows for the otherwise ungaged watershed were estimated by rescaling the daily gaged records from nearby watersheds to create a daily record for the ungaged watershed. This rescaling (sometimes termed hydrograph-matching) was typically done with data from at least two nearby gages. The rescaled estimates were compared and reviewed for consistency. If both estimates were consistent or showed very little difference, then these results were considered adequate and used for further analysis. When results differed greatly, the lower of the rescaled estimates were considered more conservative and were used in further analysis. In general, most rescaled estimates for the same period of record produced very similar results.

Daily streamflow data were aggregated to determine monthly total volumetric streamflow in the units of acre-feet. These monthly totals were used in a correlation analysis against other nearby gages in the Wood River Valley or in the Rogue River basin to fill in gaps between October 1948 and September 2000. To adequately capture variability in streamflow throughout the year, correlations were developed for specific flow regimes (low-flow or high-flow) within individual months, each season, or for all months, depending on the number of available concurrent values.

Streams that drain watersheds with different basin characteristics posed a challenge in creating an extended period of record. Most importantly, poor correlations were found between streamflow measurements in basins with differing bedrock geology. For example, Annie Creek showed no similarity to any other Wood River or Rogue River tributaries. Annie Creek streamflow measurements were extended based on temperature and precipitation data available from the Oregon Climate Service or the National Oceanic and Atmospheric Administration. Incomplete temperature and precipitation data records were extended using the same techniques employed for streamflow record extension, as described by Reid, Carroon, and Pyper (1968).

Streamflow measurements used in this investigation are available from the United States Geological Survey, the United States Department of Agriculture - Forest Service (FS), and Oregon Water Resources Department. Most USGS data are readily available in CD-form from Hydrosphere, but miscellaneous and peak streamflow measurements are mainly found in the USGS Water Resources Data Publications for Oregon, including summary and individual water year volumes. The FS has made several years of daily gaged record available on the OWRD website. Additionally, more recent years of daily gaged data and numerous miscellaneous streamflow measurements were obtained by contacting the Winema National Forest, Supervisor’s Office, in Klamath Falls, Oregon. Some miscellaneous streamflow measurements were also obtained electronically from OWRD.

Results in the Wood River Valley

Natural inflow to Upper Klamath Lake from streams in the Wood River Valley is comprised of the total inflow from the Wood River and Crooked Creek, and streams along the west side of the valley that head on the east flank of the Cascades. For Wood River and Crooked Creek, total natural inflow from these streams was found to average just more than 392,000 acre-feet per year for the 52-year period of interest. Streams on the west side of the valley were determined to have a natural inflow averaging nearly 118,000 acre-feet for the 52-year period of interest. The combined natural inflow from the Wood River Valley averages approximately 510,000 acre-feet per year for the 52-year period of interest.

Upper Klamath Lake

The current lake and marsh areas of Upper Klamath Lake and the natural lake and marsh areas of Upper Klamath Lake are presented in maps, Figures 13 and 14, on facing pages, 40 and 41.

To evaluate the natural condition of Upper Klamath Lake, materials documenting the frontier condition of the landscape were reviewed (see References). These materials, generally published under congressional authorization or published by the U.S. Geological Survey, are documents related, respectively, to the exploration of the west by the U.S. Army and the survey of western lands by USGS. The earliest of these is the report in which notes of Lt. R. S. Williamson are compiled, describing basin conditions in 1855. Although information by Williamson is generally of incidental interest, certain elements of the landscape description assisted in defining the natural lake and in visualizing the landscape.

Changes from Predevelopment Conditions

Even though certain aspects of Upper Klamath Lake appear today much as they did prior to the 20th century, the lake has changed considerably from that existing under natural conditions. Information about the natural condition of Upper Klamath Lake is not as readily available as that for Lower Klamath Lake. By 1900, many of the agricultural interests in the Wood River Valley, and water diversions, had been initiated. There was little further interest in agricultural development around Upper Klamath Lake, while that at Lower Klamath Lake was of great interest. This may explain some of the noted difference in available documentation regarding the predevelopment condition of Upper Klamath Lake. Many of the changes to Upper Klamath Lake were, nonetheless, significant. Management of the water surface elevation of the lake by regulating the outflow did not occur until 1919 by which time approximately 29,000 acres of marshland had been diked off from the natural lake. These dikes separate the lake from pasture land and have established a new perimeter for the open water surface of the lake.

Groundwater elevations are managed for these reclaimed areas by a series of drains and pumps that discharge the drainwater into the lake. Overall, the combined diking and conversion of marshland, and the regulation of the outflow, has fundamentally changed the hydraulic performance of the lake. Within the perspective of this study, an evaluation of these changes was necessary to understand how the lake responded as a natural water body to the natural inflow to the lake. Further, an understanding of changes in the watershed tributary to the lake is necessary because the natural system of the lake and watershed are inextricably linked in their consequence to the natural outflow of the lake.

Inflow Assessment

Groundwater accruals to Upper Klamath Lake were adjusted in a similar manner to that described for the climate signal adjustment for the Wood River Valley. Unmeasured and estimated groundwater discharges to Upper Klamath Lake that come from the regional aquifer would be responsive to the inferred climatically variable discharge that is exhibited by the regional aquifer. Adjustment of the groundwater discharges to Upper Klamath Lake was accomplished by using an index referenced to the Fall River discharge based on the average discharge for 1965 to 1967. This indexing period is for the same period as the Hubbard study and the period for which groundwater discharges to Upper Klamath Lake are determined (see attachment E).

Upper Klamath Lake captures a significant groundwater inflow that discharges into the lake from the regional aquifer. For the 52-year period of interest, estimated groundwater inflow averaged about 212,000 acre-feet per year. Groundwater inflow that occurs from unmeasured springs and seeps around the margin of the lake is estimated at 5,000 acre-feet per year. For the 52-year period of interest, total groundwater inflow averages approximately 217,000 acre-feet per year.

Simulation of Natural Upper Klamath Lake

Using the natural inflow to Upper Klamath Lake, the natural flow of the Link River and of the Klamath River at Keno is determined by first simulating the lake as a natural system. This determines the Link River flow, then the Keno flow is calculated based on a correlation relationship. The general objective in the simulation is to account for the following:

- Inflow to the lake
- Losses incurred to that inflow from open water surface evaporation and marshland evapotranspiration
- Storage of water remaining from this inflow
- Release of water from storage as outflow

The basis for simulation of Upper Klamath Lake is the hydrologic equation:

inflow = outflow + change in storage

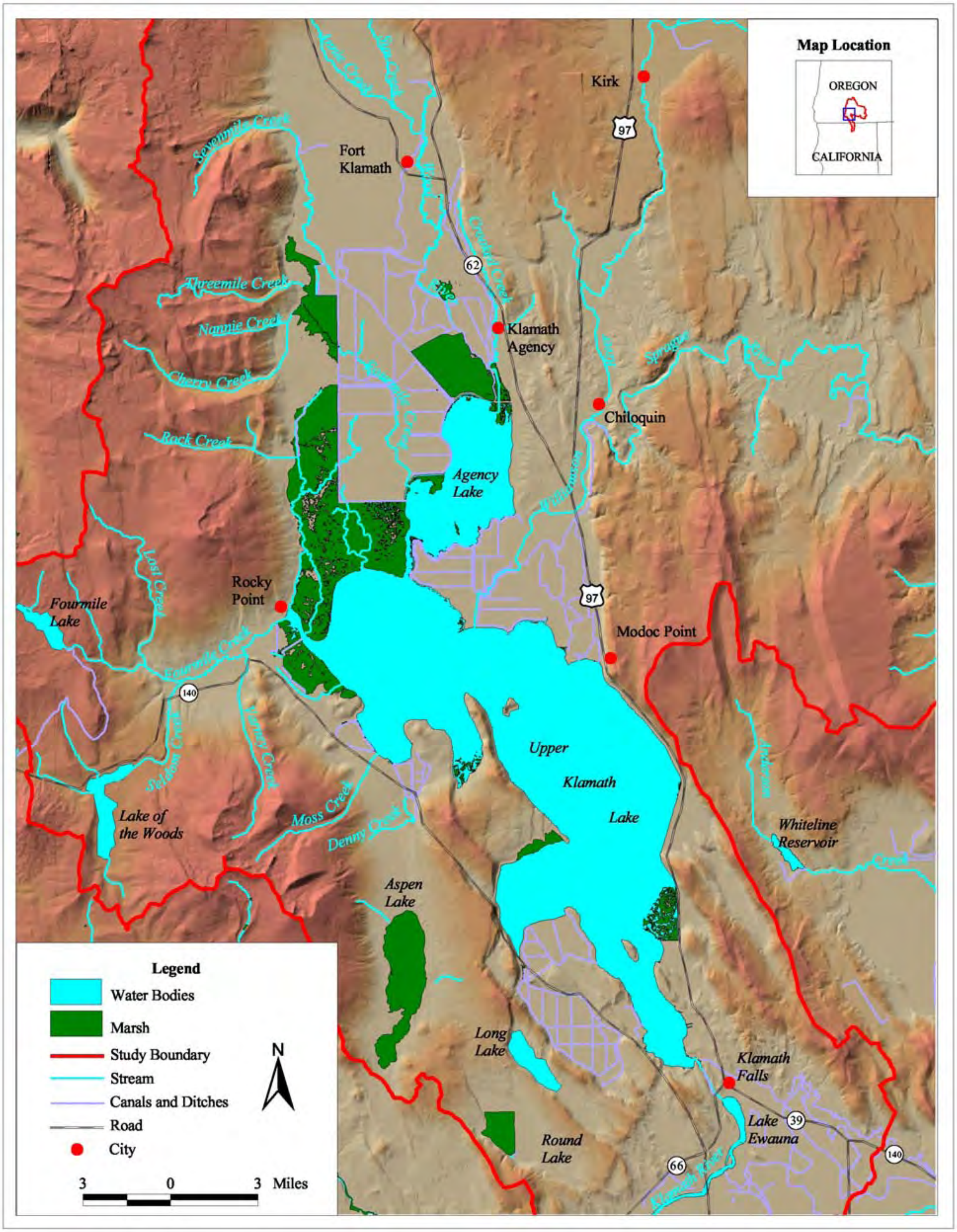

Figure 13. Current lake and marsh areas of Upper Klamath Lake.

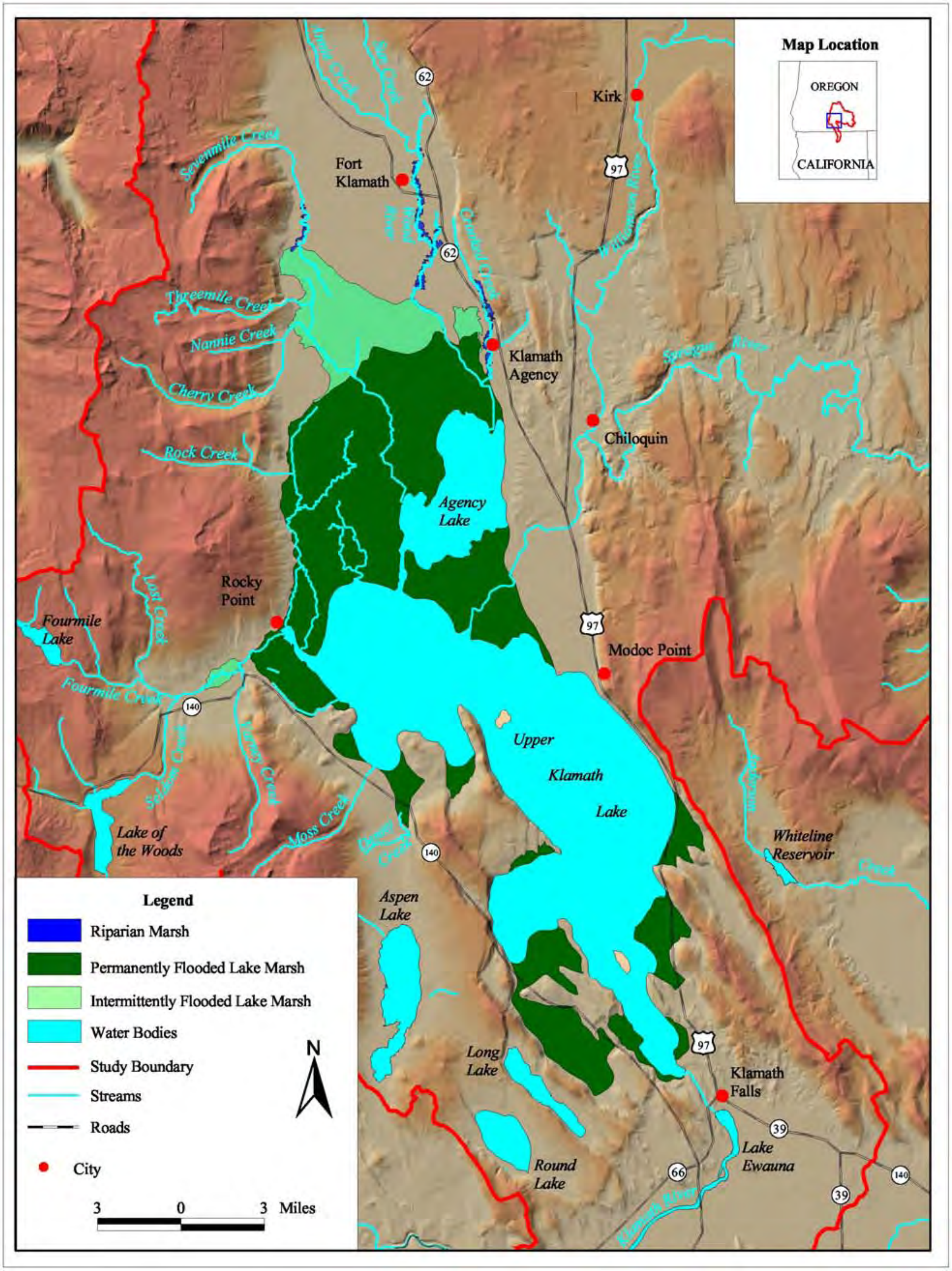

Figure 14. Natural lake and marsh areas of Upper Klamath Lake.

Further, for this study, the following definition is necessary:

net inflow = natural inflow – marsh net consumptive use – open water surface evaporation + precipitation to open water surface

A monthly accounting of net inflow and outflow for the 52-year period of record is done in units of acre-feet per month. Thus, monthly estimates of natural outflow from Upper Klamath Lake to the Link River, natural outflow from the Klamath River at Keno, and average elevation of the water surface of the lake is computed.

Factors Affecting the Outflow Response of the Natural Upper Klamath Lake

Simulation of the natural Upper Klamath Lake requires assessing several predevelopment conditions that directly affect the hydraulic response of the lake to natural inflow:

1. Predevelopment extent of the open water surface area of the lake
2. Predevelopment extent and condition of natural marshlands attendant to the lake
3. Storage capacity of the natural lake
4. Hydraulic response of the outflow from the lake due to storage-induced changes in water surface elevation

Items 1 and 2 were estimated from the interpretation of the 1906 map compiled by the USRS and the 1916 USRS plane-table survey of Upper Klamath Lake. Item 3 was estimated from the data describing the water surface area of the lake at specific given elevations of the water surface above the outlet sill, or reef. The observed (April 1904) maximum high water surface of the lake defined the estimated upper bound for the water surface area and storage capacity of the lake under natural conditions. Item 4 was evaluated from historical information relating the monthly average elevation of the lake water surface, and the concurrent discharge from the lake recorded for monthly total flow of the Link River at Klamath Falls. The groundwater accrual to the lake is also included in item 4. This groundwater inflow is derived from the regional aquifer. The assessment procedure for determining this groundwater inflow is described in attachment E. Outfall from the natural Upper Klamath Lake was determined using a third-order Runge-Kutta method. Use of this procedure effectively simulates routing of the inflow through the lake.

For the natural lake, the following estimates were developed:

Natural wetland marsh area	42,600 acres
Natural emergent marsh area	9,600 acres
Open water surface area	65,000 acres
Inundated area at maximum volumetric capacity	120,580 acres
Maximum volumetric capacity above the sill elevation	677,000 acre-feet
Lake surface elevation at maximum volumetric capacity.	4145.0 feet above USRS datum
Sustained average discharge at maximum volumetric capacity	9,320 cfs or 560,000 acre-feet/mo
Outflow depth at maximum volumetric capacity	7.2 feet (approx)
Outflow minimum discharge noted	0.0 cfs (July 18, 1918)
Outflow depth at minimum noted discharge	1.51 feet (approx)[1]

[1]Due to wind blowing up-valley and holding the lake surface adverse to discharge.

Natural inflow to the lake is stored, in part, in the natural wetland and emergent marshes and released from storage at the outlet of the lake in response to the elevation of the water surface of the lake. The integration of these factors and accounting for them is described in attachment F.

Simulation of Upper Klamath Lake

The results of the simulation of the natural Upper Klamath Lake include inflow, groundwater, losses from Upper Klamath Lake, and the natural outflow to the Link River.

Losses from Upper Klamath Lake

For Upper Klamath Lake, the net evapotranspiration from attendant natural marshlands and the net evaporation from the open water surface of the natural lake are the losses considered in this study. Marshlands are comprised of natural wetland marsh that is within or immediately adjacent to the natural lake area inundated by storage and natural emergent marsh that is subirrigated from groundwater that is associated with the natural lake. As the water-surface elevation changes in Upper Klamath Lake, the inundation area of the marshland adjacent to the lake may change (see attachment A). The marsh inundation area and the related net evapotranspiration from attendant natural marshlands are estimated as a function of the gage height of the natural Upper Klamath Lake water surface.

For the estimated 52,200 acres of marshland associated with the natural Upper Klamath Lake, net evapotranspiration averaged about 63,000 acre-feet per year for the 52-year period of record. For the same period, net evaporation from the estimated 65,000 acres of open water surface of the lake averaged about 147,000 acre-feet per year. Total loss from the lake, given average annual conditions, is nearly 210,000 acre-feet per year for the 52-year period of interest.

Resulting Water Balance for Upper Klamath Lake and Natural Outflow to the Link River

The balance of the natural inflow to Upper Klamath Lake and losses from the marshlands and the open water surface of the lake is the estimated natural outflow from the lake at Link River.

On average, for the 52-year simulation of inflow and lake losses, the balance at Upper Klamath Lake for natural lake conditions is:

Average annual natural inflow....................................	1,605,000 acre-feet
Average annual natural net loss	210,000 acre-feet
Resulting average annual natural outflow..................	1,395,000 acre-feet

The simulated monthly water surface elevations of Upper Klamath Lake are shown in Figure 15. (In Figure 15, and appropriately for other figures in this report, water year month 1949-01 is October 1948 and so on.)

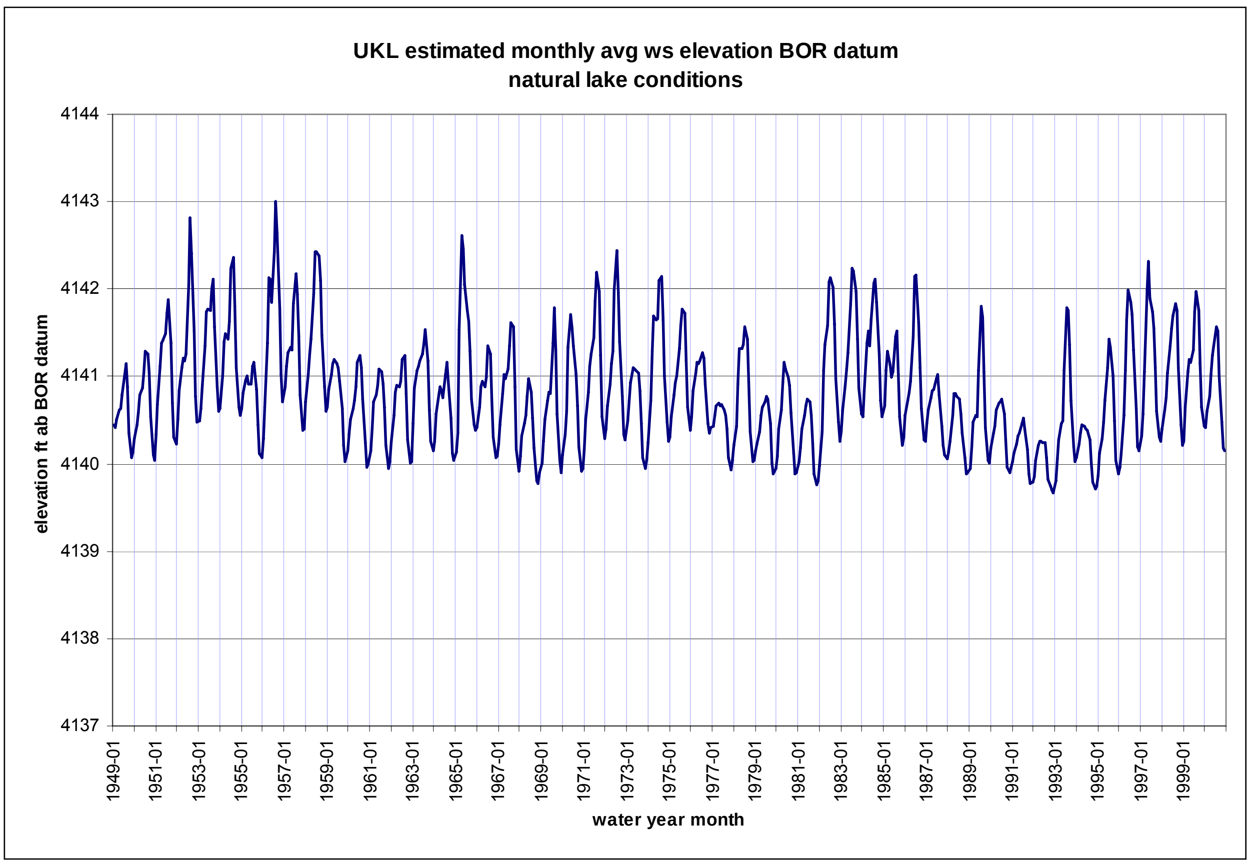

Figure 15. Simulated average monthly water surface elevation of Upper Klamath Lake estimated for natural lake conditions.

The estimated monthly outflows from Upper Klamath Lake are shown in Figure 16. Monthly average outflows during the summers of many years, such as the early 1990s, were as low as those encountered historically for the natural lake. Further, the hydrographic trace of the inflow and outflow for the study period of interest illuminates the nature of the low mid-summer outflow from Upper Klamath Lake. For years such as 1977, 1981, 1988, 1991, 1992, and 1994, significant late-spring seasonal snowmelt does not occur and the summer season natural outflow from Upper Klamath Lake was minimal.

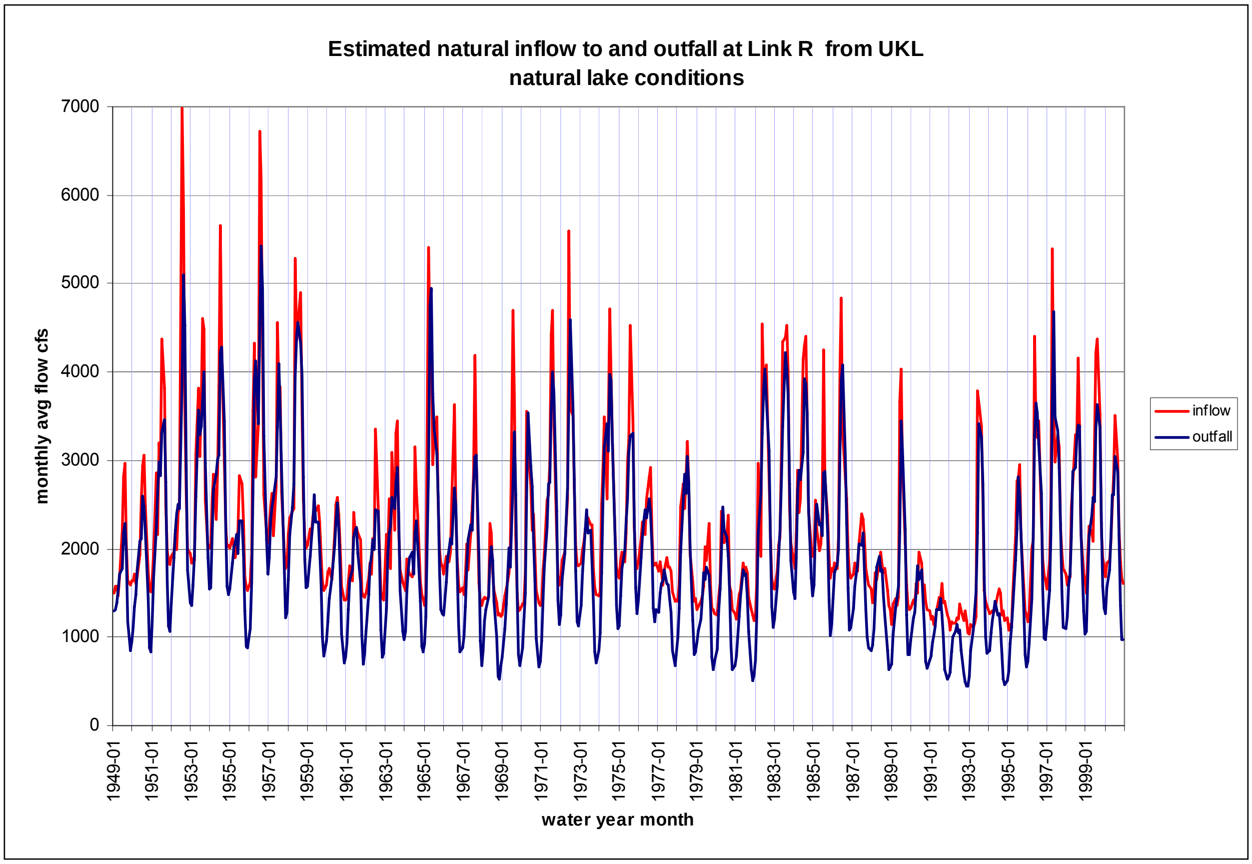

Figure 16. Simulated monthly average inflow to and outfall from Upper Klamath Lake, in cfs, estimated for natural lake conditions.

Lower Klamath Lake History

For this study, the Lower Klamath River Basin includes the Lost River Slough and Lower Klamath Lake.

Water surface elevations in Lower Klamath Lake and upstream along the channel of the Klamath River to the outlet of Lake Ewauna were controlled by a natural basalt reef in the channel at Keno. This reef held water levels in the lower lake and upstream along the channel to a minimum elevation of about 4084 feet. A similar bedrock reef at the outlet of Lake Ewauna held upstream water surface elevations about 1 foot higher, more or less, at low flow. At higher flows, backwater in Lower Klamath Lake was stored within the lake prism, which raised the water surface elevation in the complex, thereby inundating Lake Ewauna, which then became a continuous part of Lower Klamath Lake. Just at the outlet of Lake Ewauna, a natural overflow channel, the Lost River Slough also carried water out of the lake system when the water surface exceeded elevation 4085 feet (Figure 17). Aspects affecting the natural hydrologic response of Lower Klamath Lake were controlled by the following:

- Inflow from the Link River
- Evapotranspiration from extensive marshlands associated with the lake complex
- Evaporation from the open water surface existing within the lake complex
- Storage of water within the interconnected lake prism

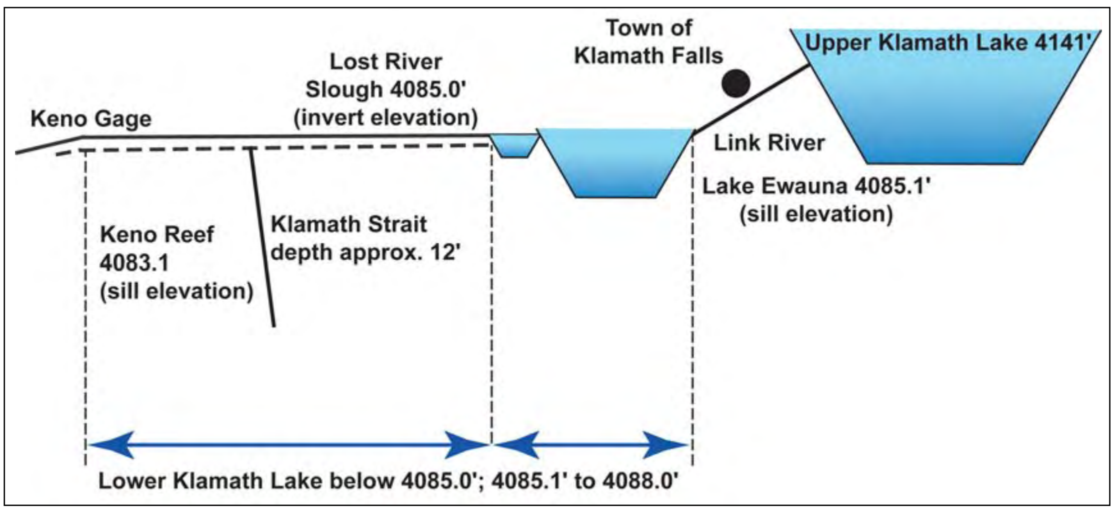

Figure 17. Water surface elevations and profiles, Upper Klamath Lake to Keno, Oregon

Inflow from the Link River supported evapotranspiration losses from the marshlands and evaporation from the open water surface. At the onset of the seasonal late-spring maximum streamflow from snowmelt and consequent maximum outflow from Upper Klamath Lake to the Link River, losses to the resulting inflow to Lower Klamath Lake were minimal. This influx of water would be stored, in part, within the lake complex, and part of the inflow would become the outflow of the lake to the Klamath River at Keno. If this seasonal inflow were sufficiently large, the elevation of the water surface of Lower Klamath Lake would be raised upstream throughout the channel of the Klamath River above Keno, and would inundate Lake Ewauna and the entrance to the Lost River Slough. For a water surface above elevation 4085 feet, this storage would cause overflow through the Lost River Slough and flow out of the Klamath Basin and into the closed basin of the Lost River and into Tule Lake. In general, the total range in water surface elevation of Tule Lake in response to this seasonal inflow was less than about 3 feet.

During a typical year, the water surface elevation for Lower Klamath Lake under natural conditions was probably about elevation 4084 to 4085 feet. During years of high snowmelt inflow, the water surface of Lower Klamath Lake may have exceeded elevation 4086 feet for a considerable time. Under these conditions, loss of storage through the Lost River Slough would have been considerable. The connection between the Lower Klamath Lake and the Lost River Slough was closed with a dike in 1890. Once the lake elevation exceeded 4085.1 feet, the present-day Lake Ewauna area was included in Lower Klamath Lake.

The current Lost River Diversion Channel was constructed primarily where the Lost River Slough had been. The channel begins at Wilson Diversion Dam on the Lost River and travels in a westerly direction, terminating at the Klamath River. The channel is capable of carrying 3,000 cfs to the Klamath River from the Lost River system. The channel is designed so that water can flow in either direction, depending on operational requirements. During the irrigation season, the predominant direction of flow is from the Klamath River.

Lower Klamath Lake

Maps of the current lake and marsh areas of Lower Klamath Lake and the natural lake and marsh areas of Lower Klamath Lake are presented in Figures 18 and 19.

Changes from Predevelopment Conditions

The natural Lower Klamath Lake was described in a very detailed planimetric survey completed by the U.S. Reclamation Service in 1905. Some changes due to agricultural development are apparent from the 1905 survey but almost all of the predevelopment aspect of the lake and its marshlands were still in place. Other documents reviewed about Lower Klamath Lake are listed in the References.

The predevelopment Lower Klamath Lake consisted of marshland and open water. Generally, the natural Lower Klamath Lake was a very shallow water body that averaged less than about 5 or 6 feet deep. Inflow to the lake was from backwater overflow of the Klamath River, through the bulrush wetland marsh adjacent to the River, and through the naturally deep channel of the Klamath Strait. Backwater control of this inflow was by the Keno reef at about elevation 4083 feet (see Figure 17). The broad, wetland marsh surrounding the central, open water area of the lake, was growing in very shallow water near the lakeshore. Two to 3 miles from the lakeshore, water was about 4 to 6 feet deep.

In deeper water and around the perimeter of the open water area, floating bulrush mats formed islands of various sizes, generally none larger than a few acres. Some narrower sections of open water were bridged by the floating mats. The greatest expanse of open water was resident in the deeper, southern portion of the lake where evaporation made the lake moderately alkaline. Further, near the end

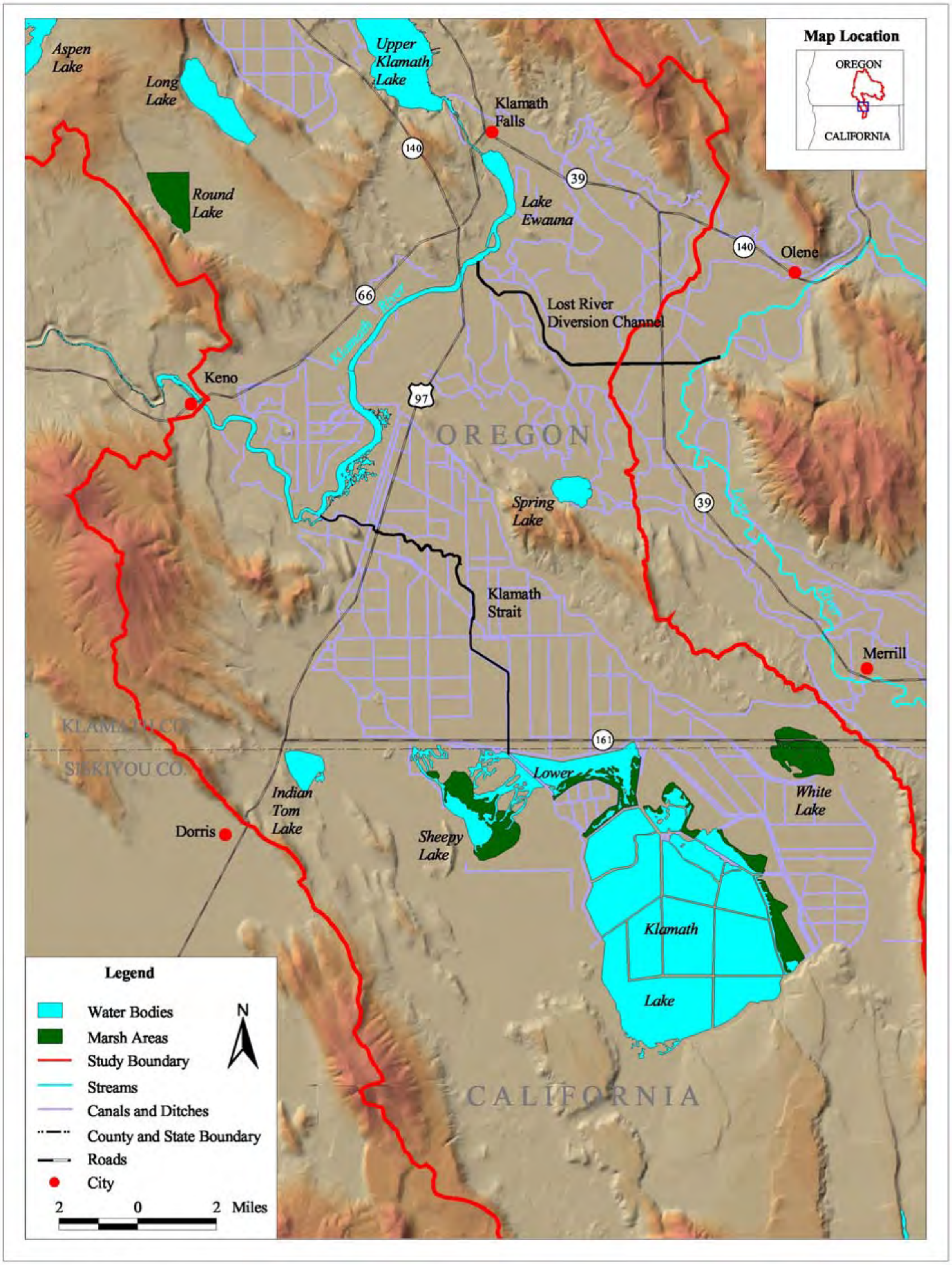

Figure 18. Current lake and marsh areas of Lower Klamath Lake.

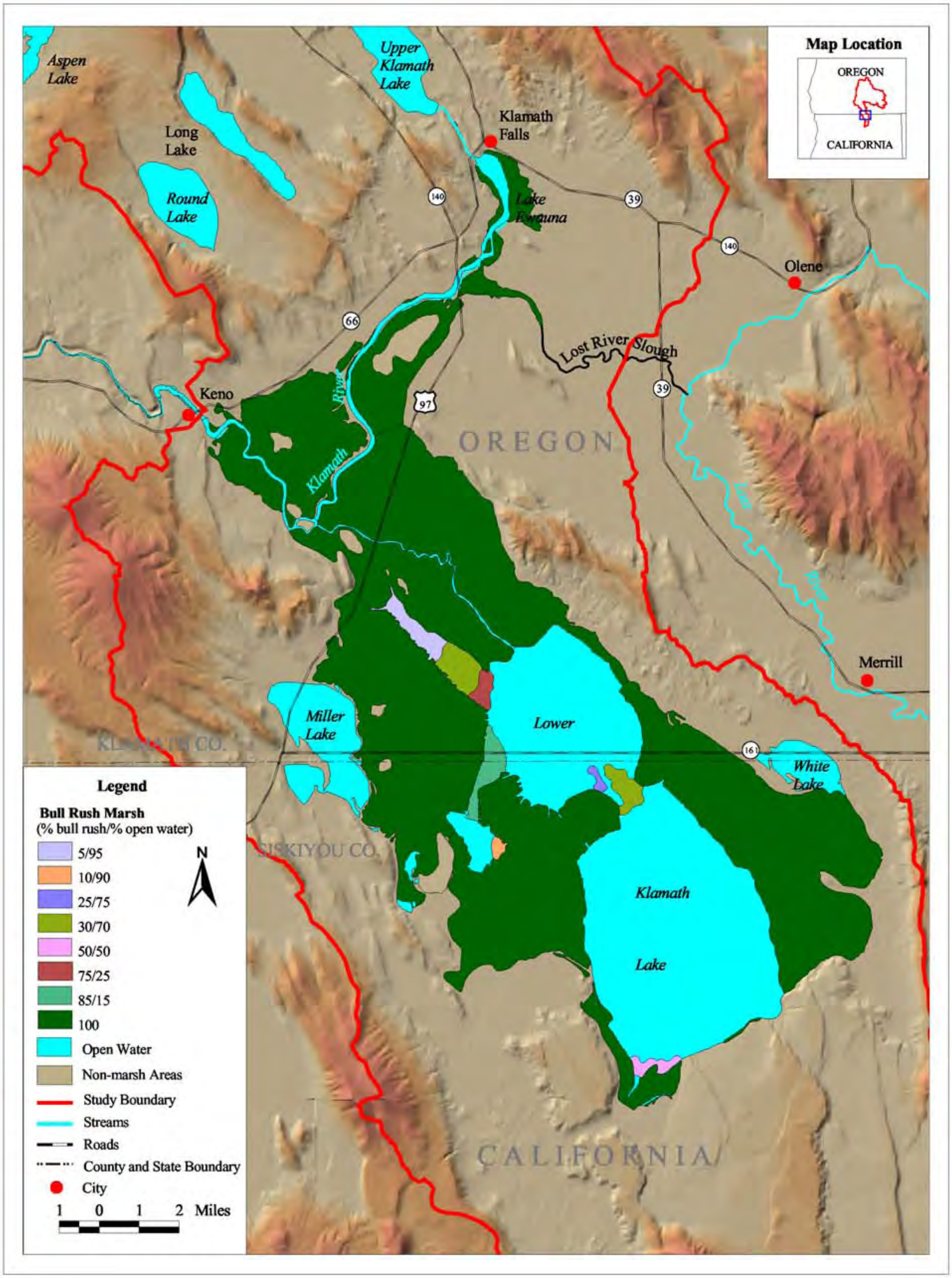

Figure 19. Natural lake and marsh areas of Lower Klamath Lake.

of the summer, warm water may have been resident especially within the more alkaline, southern part of the lake that held the deepest open water. As evaporation and marshland transpiration lowered the water surface of Lower Klamath Lake during the summer, the presence of this warm water may have been enhanced somewhat by the late-summer influx of water coming from Upper Klamath Lake. During the most typical years, the stable water surface for the lake was probably about elevation 4084 to 4085 feet.

Evidence suggests that the flood of 1888 was so great that the water surface of Lower Klamath Lake may have exceeded elevation 4088 feet for a considerable time. Under these conditions, the lake would have appeared as open water. Marshes, especially within the central portion of Lower Klamath Lake, would have been submerged. Also, the early spring influx of cold water to the lake may have fragmented much of the nearly floating mat of dormant bulrush at the edge of deeper water. At times such as this, the open water area of the lake was considerably more expansive and dominant than normal. Further, just at the outlet of Lake Ewauna at the northern end of the lake, high-water overflow of storage through the Lost River Slough would have been considerable, perhaps exceeding 1,200 cfs.

During drought, the marsh succumbed to the dry conditions and deteriorated. This may be surmised from the reported condition of the lake as reclamation of the lake floor progressed. Large islands of emergent growth would initially appear and, as dry conditions continued, these islands would become fragmented. Alkalinity in the lake would have increased and caused accelerated deterioration of the bulrush wetlands. Open water areas were somewhat shallower and, during such dry conditions, would have been warmer and more brackish. The water surface of the lake during such dry years may have been about elevation 4083 feet or lower during much of the summer.

Miller Lake, adjacent to Lower Klamath Lake on its western shore, probably received water by overflow from Lower Klamath Lake only during high-water years. During most of the time, however, Miller Lake was separated from Lower Klamath Lake by a narrow berm that defined the eastern margin of the open water surface of Miller Lake. As such, Miller Lake may be seen as being in hydraulic connection with, and receiving water from, Lower Klamath Lake by groundwater underflow. Hence, Miller Lake was a part of Lower Klamath Lake. Because of extreme evaporation, the water within Miller Lake was highly alkaline and, consequently, the water surface elevation in Miller Lake would almost always have been somewhat lower than in Lower Klamath Lake. The difference in elevation would have provided the driving force for the groundwater underflow.

In 1905, Lower Klamath Lake was planned to be reclaimed for agricultural land uses. Beginning in 1908, construction was started to place a railroad dike east of the Klamath River that would cut off all flow into Lower Klamath Lake, except flow through the Klamath Strait. By 1917, with closure of the Klamath Strait, the last phase of draining the vast area of open water and marshland of Lower Klamath Lake began. Within a decade, the natural character of Lower Klamath Lake was gone. From 1917 to the mid-1950s, the dry lakebed of Lower Klamath Lake was extensively converted to irrigated agriculture, and this reclaimed area is part of the Klamath Project operated by Reclamation. However, because the lake had been one of the most diverse ecosystems in North America, along the Pacific flyway, a part of the former lake was reflooded and is managed as a wetland complex within the Lower Klamath National Wildlife Refuge.

Inflow Assessment

Because of the complexity of the hydraulics and hydrology surrounding the Klamath River/Lower Klamath Lake interaction, completion of a simulation of the Lower Klamath Lake as part of this study was not possible. Instead, a correlation between early 1900s Link River and Keno gage measurements was developed to estimate Keno flow, based on simulated Link River flows (Figure 20). The correlation analysis, along with correlation coefficient and results, are presented in attachment F.

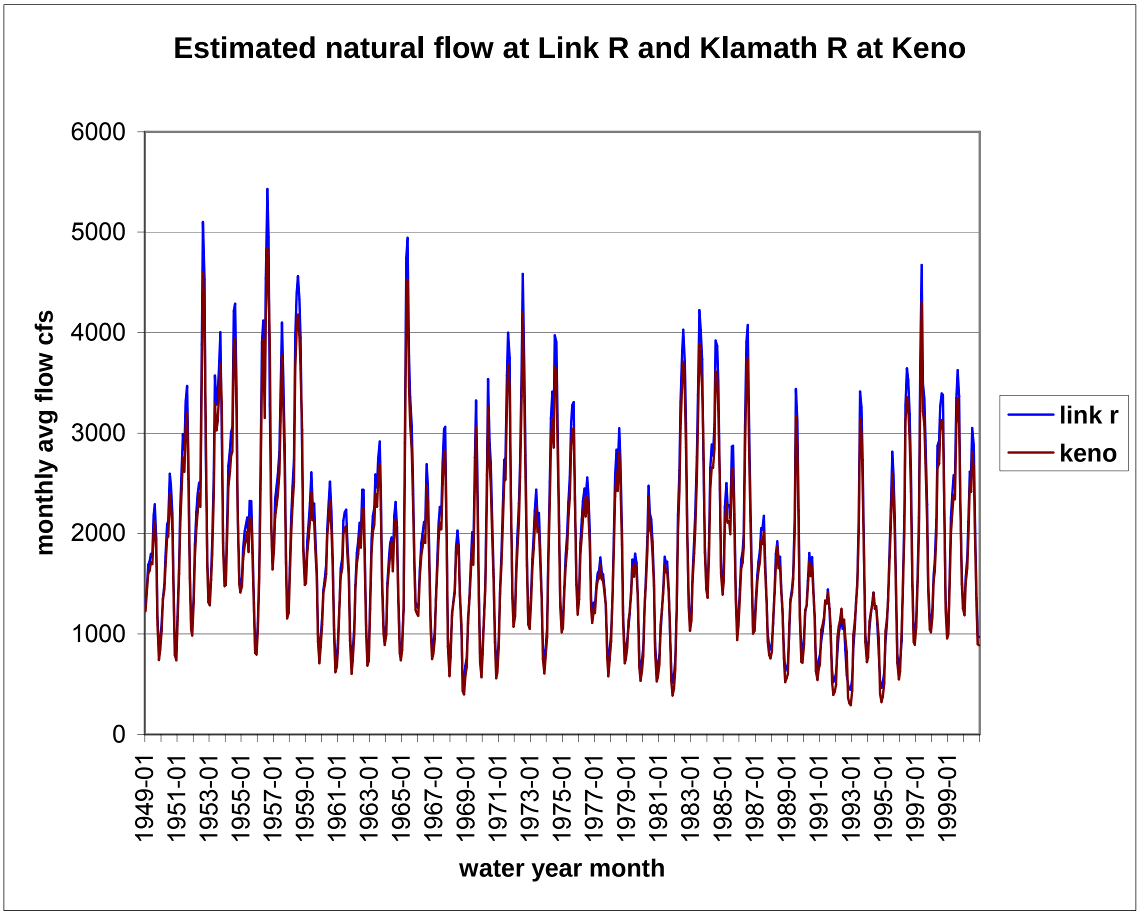

Figure 20. Simulated monthly average Link River and Keno flows in cfs.

Klamath River at Keno Gaging Station

For the simulation period, 1949 to 2000, the water balance for the Upper Klamath River Basin at Keno is described below. The natural outflow (discharge) from Upper Klamath Lake is computed in the water balance. The resulting Link River flow is then translated into an estimated flow at Keno using the correlation equations presented in attachment F. Table 4 presents the estimated inflow and outflow developed for the Link River and Keno gages.

Table 4. Estimated inflow and outflow developed for Link River and Keno gages

Upper Klamath Lake		Acre-feet
	Average annual natural inflow	1,605,000
	Average annual natural net loss	210,000
	Resulting average annual natural outflow	1,395,000
Link River to Keno		
	Average annual natural inflow	1,485,000
	Resulting average annual natural outflow at Keno gage	1,306,000

Chapter 3 —
Other Factors Considered

Other watershed factors have changed since predevelopment. Some of these factors were considered, but are unaccounted for in the assessment, such as changes in forest conditions or an extension of the flow histories before 1949.

Changes in Forest Conditions

Changes in forest conditions—predevelopment versus present-day watershed yield were items of concern expressed during the first review of this document. Present-day watershed conditions may be causing a decline in watershed yield due to fire suppression. Encroachment by juniper may be exacerbating this consequence. Other changes from natural conditions, such as beaver extirpation, forest clear-cutting and land clearing may be increasing flows by increasing watershed efficiency, but may be causing a decline in base flow.

Fire Suppression

Addressing fire suppression requires understanding several key concepts used in defining the natural flow study. Predevelopment conditions, for instance, may be defined as embracing those watershed conditions existing before settlement began. However, when settlement was initiated, development did not immediately begin or become significant and consequent changes in watershed environmental conditions were not immediately evident. Therefore, predevelopment conditions also embrace a part of the settlement period that began after about 1850. Development conditions, in general, began about 1870 and were well established by 1910. At about this time, however, fire suppression was initiated because large, uncontrolled forest fires posed a considerable threat to persons and property.

Predevelopment watershed conditions fundamentally came to an end at that time. Even so, the consequence of changes in watershed condition was not immediately evident because the environmental condition of forested areas was a relict of pre-settlement conditions. Prior to settlement, forest environmental conditions had been influenced by controlled burning initiated by Native Americans (see Leiberg, 1902). This alteration in watershed conditions by Native Americans, particularly east of the Cascades, was ubiquitous. This human activity probably affected the environment on a landscape-scale and indicates that the ecological balance and watershed conditions existing within watersheds east of the Cascades was fundamentally different than those existing naturally.

Addressing the change in forest cover is the principal element regarding fire suppression and the impact to present-day watershed environmental conditions. Watershed yield for dry-year conditions may have changed little in the absence of fire. However, the influence of fire suppression may be coupled with other factors that have affected watershed yield. The focus of the current study, however, was to address the effects of agricultural development on the landscape and on natural streamflow.

Juniper Encroachment

Western juniper favors xeric to aridic soils where soil moisture and climatic conditions indicate winters are cool and moist, and summers are dry. Annual precipitation is generally between 10 and 20 inches annually for areas favored by juniper. These trees predominantly favor terraces and flood plains, grass-shrub uplands, and rolling topography that is generally less than 5000 feet in elevation. Farther south, these trees favor similar conditions in an elevation band between 5000 and 8000 feet.

The 1930s U.S. Department of Agriculture (USDA) survey of forest resources in Washington and Oregon shows little or no juniper within the watershed area producing inflow to Upper Klamath Lake. Nevertheless, within eastern Oregon, the encroachment of juniper has been significant since about 1880. Although the reasons for encroachment are not clear, the proliferation of juniper may be related to changing climatic conditions, increases in grazing, and fire suppression. Milder climatic conditions existing after about 1850 produced a more favorable environment that enhanced the growth and succession of juniper throughout eastern Oregon. Grazing, beginning about 1860 and increasing through the early 1900s, influenced the expansion of juniper by reducing grasses and other finer fuel producing ground cover that would have provided fire-clearing of younger plants and thereby limited the expansion. Fire suppression, of course, enhanced the expansion of juniper by eliminating fire as a significant element in the natural environmental control of juniper (Getney et al., 1999; Harrington, 2003).

Within the study area, juniper does not occur within portions of the watershed that produce significant inflow to Upper Klamath Lake. Juniper expansion also does not appear to be significant within this part of the watershed during the post-settlement period. No change in watershed conditions can be substantiated regarding encroachment of juniper.

Beaver Extirpation

Somewhat conflicting indications are found regarding the presence of beaver as significant within watersheds that are tributary to Upper Klamath Lake. Robbins and Wolf (1994) quote a version of Ogden's journal for 1826-27 (as edited by M. A. Davies, 1961) indicating beaver had already been extirpated at the time Ogden ventured through the region. Reading through Davies' transcript of Ogden's journal, one finds that although Ogden found few beaver, one of his party (McKay), sent to trap in the Cascades west of Upper Klamath Lake, is reported to rejoin Ogden's returning party a short time later and had trapped several hundred beaver and otter.

These results, however, also appear in an earlier 1905 shortened and paraphrased transcription of the same journal, copied by A. C. Laut from the original in Hudson's Bay Company House, London. In general, reading through both the transcriptions by Laut and Davies, Ogden's demeanor regarding the extirpation of beaver seems motivated by his frustration and his ill health at the close of his southern Cascade venture, one for which he had hoped would have given him a better reward and better showing for his employer. His expression regarding beaver seems inconsistent with the experience of others. Nevertheless, there seems to be little objective evidence suggesting beaver had a significant presence in the Upper Klamath watershed.

Timber Removal Practices

Clear-cutting in forested areas can, potentially, increase streamflow. Well managed forest practices, however, will limit the size of the cut area and thereby limit the impact to runoff generated from the watershed. Within the moist, western slope area of the Cascades, forest regrowth is more rapid and clear-cut logging is, therefore, more intense. Logging is generally limited in the climatically drier, lower yield forested areas east of the Cascades as regrowth of clear-cut areas is slower. Within these drier areas, much of the logging activity may be related to thinning or selectively cutting older trees. Drier conditions, smaller clear-cuts, or selectively cutting and thinning older trees, may have a very limited impact to watershed conditions and may produce little or no effect on streamflow.

Records Beyond the 1949-2000 Period

Extension of the flow history (to 1905) for the Link River and Keno gages would require reconstruction of the pre-1949 missing portions of precipitation and temperature histories used in the analysis and flow histories of watersheds along the east flank of the Cascades. Prior to 1949, longer-term records that may be used in these reconstructions become increasingly limited. Consequently, several of the climatic records with longer missing periods ultimately become surrogate reconstructions of one, or two, stations that have long, continuous records. This is also true, more or less, of watershed flow histories. The end result derived from using such reconstructions may not be as reasonable as that from more recent records that were reconstructed and used in the computation of evaporation, consumptive uses, and inflow to Upper Klamath Lake.

Chapter 4 — Model Verification, Sensitivity, and Uncertainty Analysis

This chapter addresses model review and verification, numerical precision of calculations, and sensitivity and uncertainty analysis.

Model Review and Verification

The Upper Klamath River Basin Naturalized Flow Study was undertaken to determine predevelopment flows in the Klamath River at Keno, Oregon. This determination uses best available hydrologic methods and data to either measure or estimate all inflows and outflows to the system. The calculation of the Klamath River at Keno flows was accomplished using a relatively complex Microsoft Excel® spreadsheet. This spreadsheet, ukl.lkl_simulation, is clearly labeled and its documentation is provided in attachment G. This section describes efforts to verify that all links, formulae, and connections of the various sheets within the model are correctly coded. The term *model verification* describes the process of ensuring that all equations are correct and represent the model conceptualizations of the physical system.

The Excel® spreadsheet model for determining the natural flows in the Upper Klamath River Basin was checked and verified. The flow charts developed in this review accurately depict the function of the model.

Model Construction

The main tab of the model is called "calculations." The various components are brought together to achieve the desired flow determination. Seven additional tabs are used to calculate the overall inflow/outflow variables used in the "calculations" tab. Two tabs are devoted to variables for the user-defined modification of selected variables to determine the overall sensitivity of the model results to slight changes in inflow or outflow parameters. These are not recommended for use at the present time. Several additional tabs are devoted to graphics displaying model conclusions. The model acts as two separate systems that are serially connected: Upper Klamath Lake and the estimated Klamath River at Keno flows.

Model Verification

Each sheet was examined column-by-column to verify the calculations made and all connections to data in other sheets. This was done independently by the authors of the Excel® spreadsheet and a third member of the study team.

Particular care was taken to ensure new features recently added were coded correctly, including the sensitivity and groundwater functionality of the model. As the model was reviewed, a detailed flowchart was created to help visualize specific data utilization and logic throughout the model.

Model Precision

Precision carried in the calculations retains the full number of significant digits of each of the operand elements. Resulting quantities are, therefore, over-specified regarding accuracy and the reported values of these quantities exceeds their reliable accuracy. Calculations have been carried through to the most number of significant figures provided to allow the results to be traced, or specific quantities to be identified. Quantities presented in the spreadsheet ukl.lkl_simulation should generally be considered reasonable to no more than about three, or in some cases, four significant figures. As a general statement for the spreadsheets used in this study, the precision reported exceeds the reliable accuracy of the estimates.

Sensitivity Analysis

Decomposition of the Model, Data Uncertainty, and Model Sensitivity

The natural flow model was decomposed into each of the modules used in the water budget for estimating the natural flows. The effect of changing values in each of the modules may then be evaluated. An assessment tool, where the effect of implementing changes can be easily evaluated, is encoded into the model on a separate tab. This implementation is accomplished by using a staircase table showing each modular element relative to its spatial (i.e., geographic) position in the water budget. To objectively determine which of the modules need to be examined, and take advantage of the modular structure of the model, elements within the model can be assessed to determine which modules are key to the estimated natural flows at Keno. To accomplish this, two factors; namely, data uncertainty and corresponding model sensitivity, are critical to the evaluation of the general stability of the model.

For the natural flow study, data uncertainty is tied to both measured data and generated data. Two examples of measured data would be the evaporation measured by a floating pan on Upper Klamath Lake, or average monthly temperature determined for daily temperature measurements at the Klamath Falls 2 SSW meteorological station. Open water surface evaporation determined using the Hargreaves equation would be an example of generated data. Uncertainty in measured values, whether total monthly evaporation, total monthly precipitation, or average monthly temperature, is dependent on the accuracy of the measuring device and the reliability of the records. Equipment malfunction, failure to make consistent readings, and record errors all contribute to data uncertainty. The question regarding measured evaporation is to what degree the measurements were accurate.

Assuming measured evaporation is accurate, uncertainty regarding the computed values is centered upon the difference, or error, existing between the computed and measured value. However, for the example mentioned, which is computed evaporation, data uncertainty is also related to unresolved factors regarding the vapor-pressure and temperature gradients at the site, temperature of the lake, and wind, among others, which are not integrated into the calculations. Data are not readily available for these additional factors. The question regarding the adequacy of computed evaporation at a specific location is to what degree the computed values agree with concurrently measured values *at that same location*. These two general questions, namely, accuracy of measured data and the difference from measured values given by computed values, are applicable to all forms of data used in the natural flow study.

Data Uncertainty

An evaluation of uncertainty, or data error, can be completed for aspects of each of the modules in the water budget. The evaluation may include an assessment of computed evaporation, of stream gaging errors, of evapotranspiration errors for evapotranspiration determined by the modified Blaney-Criddle method, and other data used in the model. Categorization of these elements regarding their total effect on the estimated natural flow at Keno determines their significance in model sensitivity. These factors—evaporation, evapotranspiration, and gaging errors—were determined to be the most significant factors that are likely affecting sensitivity in the model. The general nature of error and uncertainty in these factors are described below.

Computed Evaporation

The Hargreaves equation was used to calculate the effective open water surface evaporation implemented in the water budget. The result for computed evaporation is effectively similar to a floating pan within a lake. Consequently, the computed evaporation was compared with concurrent measurements of evaporation from a floating pan on Upper Klamath Lake and a land pan at the Klamath Falls Weather Service Field Office (Agricultural Experiment Station), as well as with later records of the land pan at the Klamath Falls Agricultural Experiment Station. The evaluation of the Hargreaves evaporation shows that when compared to concurrent data from a floating pan, the median net difference in monthly total evaporation is about 0.3 inches. The net average difference for these calculated values is less than about 0.25 inches, and about 70 percent of the time, the net difference is within ± two times the net average difference. The absolute difference is generally within 25 percent of the measured value about 80 percent of the time, thereby indicating an approximate limiting range for uncertainty in computed evaporation of about ± 25 percent.

Measured evaporation, however, may be quite variable given local conditions and the comparison of measurements at different sites. Lake evaporation would integrate this variability over a large area. Therefore, application of floating pan data at one specific site may not provide a reasonable estimate of evaporation from the lake. To compensate for some of this variability, the lake surface was partitioned based on the nearest field weather station for which Hargreaves evaporation had been computed. Total lake evaporation for the partition was then based on the estimated evaporation at the station nearest the partition. In general, because the estimated evaporation tends to agree well with pan evaporation, field variability is expected to be due to local conditions which have been compensated, to some degree, by using the estimated evaporation at a nearby field station.

Computed Evapotranspiration

An in-depth evaluation of comparable evapotranspiration data indicates crop coefficients used in modified Blaney-Criddle method may be adjusted to give results in general agreement with studies within the field study area of the natural flow study. Published studies completed by Bidlake (1997, 2000), Bidlake and Payne (1998) Burt and Freeman (2003), and Cuenca et al. (1992) were used to evaluate the modified Blaney-Criddle method. The Bidlake studies used in-field, real-time methods to calculate marsh evapotranspiration. A reasonable assessment of uncertainty in comparison with these published sources indicates the error in the net ET estimates using Blaney-Criddle is well within about ± 20 to 25 percent.

Stream Gaging Errors

Gaging station records for the Sprague and Williamson are subject to error due to imperfect measurement of stage and determination of discharge. Stream discharge is determined from the recorded stream stage by estimation of the indicated discharge given by the stage-discharge rating curve given for the gaging station. For the Williamson, which is one of the primary gaging-station records of importance for the natural flow study, these errors are generally small as these gaging records have been rated as excellent by the USGS. In general, the error associated with the Williamson gaging records is less than about 5 to 10 percent. However, a more realistic estimate of actual error would be much less than 5 percent because monthly values were used, which are the monthly sum of daily discharges. Therefore, the measurement errors would tend to be distributed in a much narrower range about the monthly average of the daily values, and the total error is much less. For the Williamson River gaging records that were used, the error would likely be much less than 5 percent. The recommended limits for checking this error, however, are within ± 10 percent.

Model Sensitivity

Relationships regarding the significance of uncertainty are likely to be spatially and temporally variable. The key factor in determining this significance is the relative importance of each module in the transit losses suffered by inflows to the natural system. The significance of these influences to model sensitivity is related to time of year or length of time embraced over which flows are evaluated. Model sensitivity would be related to uncertainty in data regarding the most significant transit losses; namely, marsh evapotranspiration and open water evaporation.

As explained above, evaporation, evapotranspiration, and gaging errors are likely to have the most significant influence in the water budget. The effect of increasing or decreasing values in the time series for each of these elements may be examined by noting the changes in the estimated natural flow at Keno.

The Sensitivity Index

Model sensitivity is related to the effect that data uncertainty can have on computed results given by the model. For the natural flow study, model sensitivity would center on flows derived by one, or more, of the modules that may be noted in the model. Because the flows at Keno are the required result, model sensitivity for flows at Keno would be of greatest interest. A cursory evaluation of model sensitivity may be noted in relation to the difference in the calculated flow noted at Keno given baseline conditions and changed conditions in the model. The significance of this change in flow is a measure of sensitivity to the change effected in the model.

For the natural flow study, testing sensitivity embraces checking the effect of uncertainty in generated data, and the effect (in a spatial sense) of different modules that are implicated in the computed flows at Keno. The measure of potential significance in this sensitivity is indicated by the following test,

$$S_t = (Q_0 - Qa) / (Q_0 + Q_a + 1)$$

where

S_t is the sensitivity index consequent to the change
Q_0 and Q_a are the baseline flow, and altered flow, respectively.

The baseline value of S_t is S_0, which is effectively zero. In other words, if the altered condition results in no change in flow, the baseline value of the sensitivity index is maintained.

Alterations in the model will cause consequent changes in the sensitivity index. These changes are reflected in the value of the sensitivity index which can range between ± 1.0. Values of the sensitivity index less than zero reflect changes that increase the flow at Keno. Conversely, values greater than zero reflect changes that decrease the flow at Keno. These changes are reconciled against the baseline-flow condition. For a calibrated flow model, the baseline-flow condition would be the same as calibrated flow, and changes would be reconciled in the same manner. Results could be portrayed as either a time series for the sensitivity index, or as a duration plot for sensitivity threshold levels that were being evaluated. As used in the sensitivity evaluation of the model, the sensitivity index is an indicator signaling the potential significance of changes in data inputs, or changes in model parameters or function of sub-modules.

Chapter 5 — Summary

Development of the natural flows at the Keno gage was accomplished using a spreadsheet modeling approach to resolve the water budget for the Upper Klamath River Basin under undeveloped watershed conditions. Table 5 summarizes simulated monthly flows at Link River. The resulting flow duration for simulated average monthly flows for Keno gage are described in Table 6. The percentiles represent the flow exceedence ranges in monthly flow estimates at Keno solely due to record length. Table 7 represents flow exceedence ranges for Upper Klamath Lake water-surface elevation. These percentiles are most probable estimates for modeled baseline conditions and do not reflect data uncertainties for possible changes in evaporation, evapotranspiration, or other factors.

Table 5. Summary of simulated monthly flows at Link River, cfs

% Time <=	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Annual	% Time >=
10	742	1005	1199	1448	1716	1660	1764	1449	1118	727	629	669	1244	90
20	853	1104	1377	1530	1863	1795	2172	1833	1372	903	679	719	1528	80
30	936	1236	1506	1768	2044	2050	2295	2215	1757	1040	795	812	1632	70
40	1049	1351	1718	1979	2159	2203	2687	2471	2025	1302	851	836	1700	60
50	1108	1497	1806	2116	2447	2308	2816	2876	2197	1424	952	938	1913	50
60	1205	1583	1929	2239	2608	2560	3265	3068	2590	1553	1073	1034	2049	40
70	1298	1649	2139	2378	2815	2934	3413	3396	2883	1776	1228	1126	2322	30
80	1379	1847	2213	2602	3071	3379	3923	3672	3367	2224	1426	1286	2528	20
90	1562	1937	2515	2886	3574	3652	4215	4028	3753	2740	1754	1489	2651	10

Table 6. Summary of simulated monthly flows at Keno, cfs

% Time <=	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Annual	% Time >=
10	648	1088	1216	1408	1647	1577	1670	1408	1168	631	520	560	1188	90
20	769	1159	1352	1472	1767	1689	2017	1721	1358	822	578	616	1429	80
30	857	1255	1453	1667	1925	1907	2125	2051	1664	964	706	720	1528	70
40	974	1342	1625	1845	2016	2040	2477	2280	1890	1228	767	746	1607	60
50	1033	1455	1698	1964	2343	2133	2595	2649	2039	1349	873	854	1773	50
60	1131	1523	1803	2072	2410	2360	3009	2827	2388	1478	998	955	1903	40
70	1224	1576	1984	2196	2615	2703	3146	3131	2657	1706	1154	1049	2169	30
80	1304	1739	2049	2399	2829	3115	3615	3385	3104	2210	1351	1210	2347	20
90	1488	1815	2319	2659	3294	3367	3877	3707	3460	2923	1684	1412	2511	10

Table 7. Summary of simulated monthly Upper Klamath Lake water surface elevation, feet

% Time <=	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	% Time >=
10	4140.0	4140.2	4140.4	4140.6	4140.6	4140.7	4140.7	4140.6	4140.3	4140.0	4139.9	4139.9	90
20	4140.1	4140.3	4140.5	4140.6	4140.7	4140.8	4141.0	4140.8	4140.5	4140.1	4139.9	4139.9	80
30	4140.2	4140.4	4140.6	4140.8	4140.8	4141.0	4141.1	4141.1	4140.7	4140.2	4140.0	4140.0	70
40	4140.2	4140.4	4140.8	4140.9	4140.9	4141.1	4141.3	4141.3	4140.9	4140.4	4140.1	4140.0	60
50	4140.3	4140.6	4140.8	4141.0	4141.1	4141.2	4141.4	4141.5	4141.0	4140.5	4140.2	4140.1	50
60	4140.4	4140.6	4140.9	4141.1	4141.2	4141.3	4141.7	4141.6	4141.3	4140.6	4140.3	4140.2	40
70	4140.4	4140.7	4141.0	4141.2	4141.3	4141.6	4141.8	4141.8	4141.5	4140.8	4140.4	4140.3	30
80	4140.5	4140.8	4141.1	4141.3	4141.5	4141.8	4142.1	4142.0	4141.8	4141.1	4140.5	4140.4	20
90	4140.6	4140.9	4141.3	4141.5	4141.7	4142.0	4142.2	4142.2	4142.0	4141.4	4140.8	4140.6	10

The simplified flowchart in Figure 4 earlier has been completed as Figure 21, with average annual values shown from each source.

Data tables of sources showing synthetic natural streamflow records, with monthly streamflows in acre-feet are presented in attachment H. The synthetic natural streamflow at Keno gage is also presented in units of cfs.

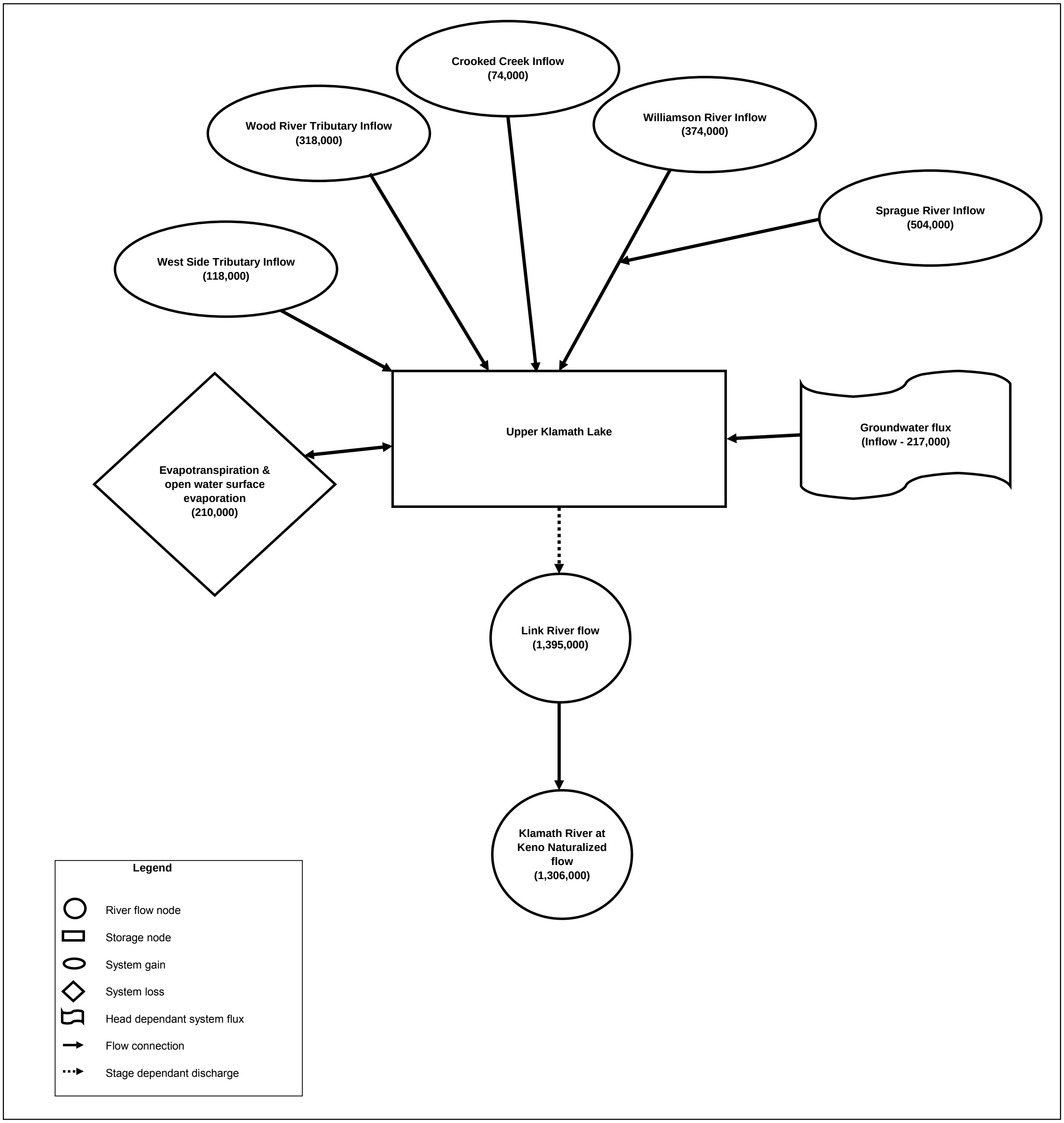

Figure 21. Simplified flowchart of how natural flows were estimated with average annual values shown.

References

The references are sorted by category:

- Evapotranspiration and consumptive use calculations
- Evaporation calculations
- Wood River Valley
- Correlation methods
- Historical conditions
- Additional references
- Maps and drawings
- All Areas (Water Supply Papers)

References for Evapotranspiration and Consumptive Use Calculations

Allen, R.G., L. S. Pereira, D. Raes, and M. Smith. 1998. *Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements.* FAO Irrigation and Drainage Paper 56. Food and Agriculture Organization of the United Nations.

Berger, David L., Michael J. Johnson, and Mary L. Tumbusch. 2001. *Estimates of Evapotranspiration from the Ruby Lake National Wildlife Refuge Area, Ruby Valley, Northeastern Nevada, May 1999 – October 2000.* Water Resources Investigations Report 01-4234, Prepared in cooperation with Nevada Division of Water Resources and the U.S. Fish and Wildlife Service, Carson City, Nevada.

Bidlake, William. December 2000. "Evapotranspiration from a Bulrush-Dominated Wetland in the Klamath Basin, Oregon," *Journal of the American Water Resources Association, Vol. 36, No. 6*, Tacoma, Washington.

Bidlake, W. R. and K.L. Payne. 1998. *Evapotranspiration from Selected Wetlands at Klamath Forest and Upper Klamath National Wildlife Refuges, Oregon and California.* U.S. Geological Survey Administrative Report, Tacoma, Washington.

Burt, Charles, and Beau Freeman. May 2003. *Hydrologic Assessment of the Upper Klamath Basin Draft Report*, Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo, California.

CH2M Hill. September 1983. *Salinity Investigation of the Price-San Rafael Rivers Unit*. Colorado River Water Quality Improvement Program. Bureau of Reclamation. Department of the Interior.

Cuenca, Richard H. June 1992. *Oregon Crop Water Use and Irrigation Requirements*, Department of Bioresource Engineering, Oregon State University, Corvallis, Oregon. pp. 128 – 130.

Freeman, Beau. 2005. E-mail correspondence. July 2005.

Jensen, M.E., R.D. Burman, and R.G. Allen. 1990. *Evapotranspiration and Irrigation Water Requirements*. New York: American Society of Civil Engineers. p 234.

USDA, Soil Conservation Service. September 1970. *Irrigation Water Requirements*. Technical Release No. 21.

References for Evaporation Calculations

Agrimet Historical Archive Weather Data Access. Retrieved June 24, 2003, from the Bureau of Reclamation web site: http://www.usbr.gov/pn/agrimet/webarcread.html

Future Water, Science for Solutions in Sustainable Water Management. Retrieved November 3, 2003, from the FutureWater web site: http://www.futurewater.nl/projects/etref.htm

Hargreaves' Equation. Retrieved June 5, 2003, from the Civil Engineering, University of Waterloo web site: http://www.civil.uwaterloo.ca/watflood/Manual/02_03_2.htm

Linsley, Ray K. Jr., Max A. Kohler, and Joseph L. H. Paulhus. 1982. *Hydrology for Engineers*. New York: McGraw-Hill Book Company. p. 508.

Penmanetc. Retrieved June 5, 2003, from the Stockholm University Biogeochemical Modeling Node of the Land-Ocean Interactions in the Costal Zone Project of the International Geosphere Programme of the International Council of Scientific Unions web site: http://data.ecology.su.se/MNODE/Methods/penman.htm

Snyder, R. L. 2002. NWSETO: User's Guide and Program Documentation. Retrieved November 3, 2003, from The University of California, Davis web site: http://biomet.ucdavis.edu/evapotranspiration/NWSETo/NWSET0.htm

References for the Wood River Valley

Frank, F.J., and A.B Harris. 1969. *Water-resources appraisal of Crater Lake National Park, Oregon.* U.S. Geological Survey Open-File Report 69-0095, 26 p.

Hathaway, R.L. 2003. Personal communication.

Hathaway, R.L., and R.M. Todd. 1993. *Wood River Sub-Basin Water Quality Related to Land Use Associated with Forest and Livestock Grazing: Klamath Falls*. Oregon State University Agricultural Extension Service, Water Resource Research Institute. 25 pp.

Hubbard, L.L. 1970. *Water Budget of Upper Klamath Lake, Southwestern Oregon.* U.S. Geological Survey Hydrologic Investigations Atlas HA-351, scale 1:250,000.

Williams, H. 1956, Crater Lake, on reverse of Crater Lake National Park and Vicinity, Oregon Quadrangle. U.S. Geological Survey Topographic Map, scale 1:62,500 (single sheet).

USDA, Forest Service, Winema National Forest. 1994. *Watershed Analysis Report for the Rock, Cherry, and Nannie Creek Watershed Area, Pacific Northwest Region.*

USDA, Forest Service, Winema National Forest. 1995. *Watershed Analysis Report for the Threemile, Sevenmile, and Dry Creek Watersheds, Pacific Northwest Region.*

USDA, Forest Service, Winema National Forest, Klamath Ranger District. 1996. *Watershed Analysis Report for the North Fourmile Watershed, Pacific Northwest Region.*

References for Correlation Methods

Lapin, L. L. 1983. *Probability and Statistics for Modern Engineering*. Belmont, California: Wadsworth, Inc. (PWS Publishers). p. 348.

Pollard, J. H. 1977. Linear regression through the origin or some other fixed point In *A Handbook of Numerical and Statistical Techniques with Examples Mainly from the Life Sciences*. Cambridge: Cambridge University Press. 349 pp.

Reid, J. K., L. E. Carroon, and G. E. Pyper. 1968. *Extensions of Streamflow Records in Utah.* Utah Department of Natural Resources. Technical Publication No. 20. 105 pp.

Troutman, Brent M., and Garnett P. Williams. 1987. Fitting Straight Lines in the Earth Sciences, Chapter 7 In *Use and Abuse of Statistical Methods in the Earth Sciences*. New York: Oxford University Press, pp. 107-28.

Williams, G.P. 1983. Improper use of regression equation in the earth sciences. *Geology*, Vol. 11, No. 4. pp. 195-197.

Zebrowski, E., Jr. 1979. *Fundamentals of Physical Measurement*. Belmont, California: Wadsworth Publishing Co. (Duxbury Press). p. 130 ff.

Sensitivity Analysis

McCuen, R.H. 2003. *Modeling Hydrologic Change: Statistical Methods*. Lewis Publishers, CRC Press, Boca Raton, Florida, 433 p.

Salas, J.D. 1993. “Analysis and modeling of hydrologic time series.” In *Handbook of Hydrology*, Maidment, D.R. (ed.), McGraw-Hill, New York, Ch. 19, pp. 19.1-19.72.

References for Historical Conditions (with some annotation)

LRS = Lost River Slough
LKL = Lower Klamath Lake
UKL = Upper Klamath Lake

UKL/LKL: Abbot, Lieut. Henry L. 1857. Explorations and Surveys, to Ascertain the Most Practicable and Economic Route for a Railroad from the Mississippi to the Pacific Ocean, 1854-5, The Sacramento Valley to the Columbia River. War Department, Washington: Government Printing Office, p. (?)

Contains descriptions of area by early explorers. See Part 1, p.28: “The chain of Klamath water is an interesting feature of this region. . . .Colonel Fremont, in his expedition of 1843-44, crossed the principle tributary to this [Klamath] marsh. He describes it as a stream thirty feet wide, and from two to four feet deep. . . . After passing through a canon . . . it spreads out into a fine sheet of water, called Upper Klamath Lake. This lake receives several smaller tributaries. The river leaves it near its southern point, and soon winds through a marsh, which forms the northern portion of Lower Klamath Lake. Lieut. Williamson, with a detached party, examined this portion of it course, and his opinion was, that in seasons of high water the marsh is overflowed and the river can properly be said to flow through the lake. In summer, however, its bed is very distinct, and it does not join the sheet of water forming the lake." Pages 66-72 have some descriptions of lake area. Chapter IV LKL Williamson explorations pages 76-77, "August 14 . . . skirted western side of the lake. . . .The body of water was small, but a large marsh extended for about 10 miles towards the north." "August 15 . . . The river comes into the marsh, curves through it, and passes off to the canon, without any visible connection with the main body of the lake, which lies further southward. Doubtless, in the rainy season, the water covers the whole marsh, and then the river literally passes through the lake." "August 16 . . . came at noon to an arm of a large lake from which the river flowed. This proved to be Upper Klamath Lake. It was difficult to say where the connecting river ended and the lower lake began. Where the tules ceased, the river ran rapidly between low hills backed by higher ridges and was full of rapids. In one place there were falls from five to ten feet high. We found the river everywhere too deep to ford. At the rapids, where many rocks rose above the water, there were numerous deep holes; and near where it emerged from the lake it was twenty feet deep."

Part III, Botanical Report, Chapter 1, p.17. Shores of the Klamath Lakes. "The immediate borders of the lakes are covered with a growth of tule. . . . On drier ground but still in the vicinity of the water, are thickets composed of Pyrus rivularis, Prunus subcordata, Rhamnus Purshianus, and wild cherry. . . . The number of trees in this vicinity is small. A few cottonwoods and willows are found in the neighborhood of the water. . . ."

LRS: Abney Robert, M. 1964. A Comparative Study of the Past and the Present Condition of Tule Lake. Bureau of Sport Fisheries and Wildlife Tule Lake NWR, Tule Lake, California. Provided historical information on Lost River Slough.

P. 3: "A flood in the spring of 1890 gushed Klamath River water down Lost River Slough deep enough to swim a horse for about six months and brought Tule Lake to its last historic high water level of 4064 feet. …the Klamath River periodically flooding down the Lost River Slough is the main source of water which caused Tule Lake's historic high levels. The natural control of this Klamath River flowage into Tule Lake was regulated by the amount of spill over the reef from Upper Klamath Lake and the amount of river flowage over the rapids at Keno." P. 5: "Even with the lake level at 4076 feet, Tule Lake was about 10 feet lower than the Klamath River and served as a storage reservoir of Klamath River water via the Lost River Slough." P.6: "Following the high water of 1890, J. Frank Adams, Jessie D. Carr and a company of Tule Lake ranchers built a mile long dike along the east bank of the Klamath River to stop the flow of Klamath River into Tule Lake via the Lost River Slough and Lost River."

UKL/LRS: Atkins, Glen J. 1970. The Effects of Land Use and Land Management on the Wetlands of the Upper Klamath Basin. MS Thesis, Western Washington State College. 122 p.

Has discussion of preexisting wetlands, Lost River Slough, physical setting, vegetation, and historical development.

LKL/UKL: 1965. As told to me… *Klamath Echos*, 1(2):11.

"By the summer of 1905 we find Mr. Woodberry associated with M. G. Wilkins in the Klamath Navigation Company, which launched the steamer on August third for service between Klamath Falls and Lairds Landing on Lower Klamath lake. At this time the McCloud the McCloud Railroad was building toward that point, and the steamer became a link in the following transportation system: Steamer Klamath from Klamath Falls to Lairds Landing (50 miles). . . ."

As told to me… by George Stevenson. April 12, 1953.

"I bought the old dredge from Southern Pacific in 1914. They had used it building the Ady fill across Lower Klamath Lake. Must have moved it to the Upper Klamath Lake about 1908. Its name was the Klamath Queen. The Southern Pacific used it on their right of way along the Upper Lake. I bought it after the work was finished. I used it on building dykes; built about one hundred miles of dykes on the Upper Lake and Agency Lake."

LKL: 1965, As told to me…by John Yaden, February 3, 1948. *Klamath Echos* 1(2): 20-21.

"I came here in 1901. . . . It was for the steamer Klamath that the channel was dredged to Laird's Landing. Previous to this all landings had been at Mosquito Point, about two miles northeast of Laird's and Chalk bluffs about one mile further. I ran both the Ewauna (40 feet in length) and Tule (25 feet in length) on Lower Klamath and used the Adams Tule Cut into White lake in carrying Reclamation officials to various places. There was also a landing northwest of Lairds, 1 ½ to 2 miles where no dredging was necessary for boats to land. This may have been called Indian Bank landing . . . may also have been called Coyote Point or Oklahoma Landing I later times. There was another landing reached through Sheepy Lake that required no dredging. This landing was the one possibly used by the Fairchild Ranch." (See 1905 maps for places and possible inference of date.)

UKL/LKL: Boyle, John C. 1976. *50 Years on the Klamath*. Medford, Oregon: Klocker Printery. 59 p. (Information on project history, e.g., 1918)

UKL: Carlson, J.R. 1993. "The Evaluation of Wetland Changes around Upper Klamath Lake, Oregon, Using Multitemporal Remote Sensing Techniques," Chapter 6 In Campbell, S.G., editor, *Environmental Research in the Klamath Basin, Oregon, 1991 Annual Report*. U.S. Department of the Interior, Bureau of Reclamation, Denver Office, R-93-13, 212 pp.

LRS/LKL/UKL: Cleghorn, John C. 1959. *Historic Water Levels of Tulelake, California-Oregon and their Relation to the Petroglyphs*. Klamath County Museum Research Papers, No. 1. 11 pp.

This provided information on the Lost River Slough and also comments about reefs at UKL and Keno (p.2) (i.e., "overflow did not occur [at Keno] except in flood times." Reference to making a survey of Lower Klamath Lake in 1908 "before it was drained" (p.6).

UKL/LKL: Gatschet, Albert Samuel. 1966. An Extract from the Klamath Indians of Southwest Oregon (facsimile): Ethnographic Sketch of the Klamath Indians of South West Oregon. From *Contributions to North American Ethnology*, Vol. 11, Part 1. Washington DC: Government Printing Office. 1890.

LKL: Helfrich, W.H. 1965. As told to me…by Judge U.E. Reder. Recorded March 3, 1948. *Klamath Echos* 1(2):18-19:

"I came here in 1895 and began boating about 1900. They just piled the freight up and we would take two fifty-ton barges to bring it back. . . . Most of the lumber used in building Merrill and the surrounding ranches was brought by boat from McCormak's Mill at Keno to White Lake, not by wagon as most people think.

We always tried to haul lumber to the lower lake in the spring when the water was running through the straits into Lower Klamath Lake. And in the fall, we hauled hay from Oklahoma through the straits into the river, when the water was draining out of the Lower Lake. . . .On White Lake there used to be humps all over and what time we were not stuck in the mud, we were out in hip boots hunting a channel."

"The Van Brimmer ditch drained White lake so far that Frank Adams attempted to get water from Lower Klamath. At first he tried to open up a channel from Lower Klamath Lake by cutting the sod with hay knifes, but it didn't work. So later he got a dredge. . . . The Adams dredge was used on Adams cut from Lower Klamath Lake to White Lake, on the cut to Laird's Landing and on the fills for the railroad across the swamp at Ady. It was also used south of town here diking Lake Ewauna."

"…The Canby or its barges never drew more than three feet of water if that much. They were flat bottomed, so they could go over the old Indian rock ledge near the Kesterson mill."

FISH RUNS: *Klamath Republican*. March 21, 1901:

"Those who like to see fish, immense congregations of them . . . ought to be here now. . . . These enormous drove of fish can now be seen not alone here, but in the rivers and creeks generally throughout the country. Mulluts, rainbow trout and salmon-splendid fish, giants of their size and apparently anxious to be caught. This phenomenon will last a month, and until their egg-laying camp meeting is over with. After that the fish will be distributed over a wider space and will be in plenty the year through."

LKL: *Klamath Republican*. June 8, 1905: "The boat [Klamath] is 75 feet long with a 16 foot beam. The hold has a depth of four feet. It draws three feet, two inches of water, and will carry about 75 tons."

LKL: *Klamath Republican*. October 12, 1905:

". . . the Klamath would make a trip to the Lower Lake in a few days. Next week they would begin regular round-trips daily between Laird's Landing and Klamath Falls. . ."

Klamath Republican. October 26, 1905: "The steamer Klamath started Monday, on tri-weekly trips to Laird's Landing. . ."

LKL: 1965. *Klamath Echos* 1(2):66-67: "Merrill Landing may have seen use during high water seasons, by boats of shallow draft, even before 1903."

"White Lake City Landing. Founded in 1905, White Lake City probably had a landing of sorts at certain times of the year for a short period of time."

"Oklahoma Landing. At Coyote Point, north of Laird's Landing about three miles. Received lumber and supplies for homesteaders . . . beginning about 1889."
"Sheepy Lake Landing. . . . supply point on Sheepy Creek, which ran into Sheepy Lake, which in turn connected with Lower Klamath Lake."

"Laird's Landing. . . . not opened to water traffic until the late summer of 1905. And then only after a channel was dredged from the open water of Lower Klamath Lake. . . . saw considerable freight traffic use for a few years also, or until the spring of 1908, when railhead had reached Mt. Hebron and Dorris and the traffic then went the way of Teeter's Landing."

"Teeter's Landing. About four and a half miles south of Keno, it came into existence by 1889 or before. . . . But the end was in sight, on January 1, 1909, Teeter's Landing or Blidel, was bypassed be the new shipping point of Holland, where the railroad crossed the Klamath Straits, running out of Lower Klamath

Lake. . . . There was another "Holland" in western Oregon, so the name Ady came into being."

UKL: Landrum, Francis S. 1988. *Guardhouse Gallows and Graves* (about Fort Klamath Area).

LKL: Marcotte, Joseph B. 1968. Lake Stage Determination for Lower Klamath Lake (1904-1917). Letter to Reclamation Files. 4 p.

Has information on Keno gage readings and Lower Klamath Lake surface elevations, comments on letter indicate, ". . . Keno gage readings represent very closely the lake levels. . . ." Has figure with Lower Klamath Lake elevation vs Q at Keno. Drawing number 12-201-4448.

Oregon, State of. 1905. Illustrated History of Central Oregon embracing Wasco, Sherman, Gilliam, Wheeler, Crook, Lake, and Klamath Counties. Part VII. Spokane, Washington: Western Historical Publication Company.

UKL: Riseley, John C. and Antonius Laenen. 1999. Upper Klamath Lake Basin Nutrient-Loading Study, Assessment of Historic Flows in the Williamson and Sprague River. USGS, Water Resources Investigations Report 98-4198. 22 pp.

LINK: *Sacramento Bee*. February 26, 1959.

Article mentions that in Gatschet "Indians scooping up fish from the dry bed of the stream when south wind stopped the waters from flowing from the lake to the river." This quote taken from newspaper referencing Spier's Klamath Ethnolography (*Sacramento Bee,* February 26, 1959?) from Klamath County Museum. Also in this article was a quote from William Clark, "who was piloted about the area by the late Captain Oliver C Applegate. . . . The peculiar fact is that Link or Yulalona River is occasionally blown nearly dry, and the water is blown back into the lake when a strong south wind blows." Ray Telford and others here before the time they . . . built a power dam across the Link River confirm this report. The rushing waters of Yulalona [Link] River actually were held back in the lake as the wind roared up the canyon. . . ."

Spier Leslie. 1930. Klamath Ethnogeography, University of California Publications in *American Archaeology and Ethnology*. Vol. XXX. 338 pp.

LKL/LRS: Reclamation. 1910. Specifications No. 170 Accession No. 12379, Drawing No. 1 and 2, July 1910, In *Advertisement, Proposal and Specifications, Klamath Project, Oregon-California, Lost River Diversion Channel*.

Original construction drawings for Lost River Diversion Channel Canal. Shows dike of 1910 on Klamath River side of Lost River Slough and shows profile along route of channel as well as river water elevations. Also shows RR connections across Lower Klamath Lake July 1910 (on location map).

LKL: Reclamation. 1944. Klamath Straits Drain Outlet Maps 12-D-393, 12-D-385, 12-D-383, and 12-D-384, Klamath Project, Oregon-California. Tule Lake Division, Modoc Unit.

Original reconstruction drawings for Klamath Straits Drain. Provides some information on depth of straits drain. Original ground surface was probably "base of mud" as shown on plans. Drain was dry from 1917 to 1944 when reconstruction began. Jim Bryant, personal communication.

LKL: Voorhees, I.S. 1913. History of the Klamath Project, Oregon-California from May 1, 1903 to December 31, 1912. 175 p.

Contains description of marsh lands, Keno cut, natural reef at Keno (4084 feet), and reference to Quinton's 1908 report.

LKL: Weddell, B.J. 2000. *Relationship Between Flows in the Klamath River and Lower Klamath Lake Prior to 1910*. Report for USFWS Klamath Basin Refuges. Tulelake, California. 10 pp.

Review of historical accounts. Describes early Lower Klamath Lake and relation to Klamath River. Has good bibliography. Good discussion of Information sources.

LKL: Quinton, J.H. 1908. Report on Reclamation of Marsh Lands, Klamath Project. Reclamation. Quinton's estimate of natural spring flow to Upper Klamath Lake did not include a pan coefficient for assessing evaporation.

Information on mapping Lower Klamath Lake and reference to springs around Lower Klamath Lake).

Additional References

Bach, L. 2004. Personal communication with Thomas Perry.

Chow, Ven Te. 1959. *Open Channel Hydraulics*. New York, McGraw-Hill Book Company. Chapter 5, Development of Uniform Flow and its Formulas, p89-127.

Chow, V. T., Maidment, D. R., and Mays, L. W. 1988. *Applied Hydrology*, McGraw-Hill Book Company, New York. p. 252 ff.

Davies, M. A. 1961. *Peter Skene Ogden's Snake Country Journals, 1826 – 27*. London: Hudson's Bay Record Society.

Emshoff, J. R. and R. L. Sisson. 1970, *Design and Use of Computer Simulation Models*. New York: The Macmillan Company. 302 pp.

Gannett, M. W., Lite, K. E., and La Marche, J. L., 2003, Temporal and spatial variations in groundwater discharge to streams in the Cascade Range in Oregon, and implications for water management in the Klamath Basin: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 487.

Gedney, Donald R., David L. Azuma, Charles L. Bolsinger, and Neil McKay. 1999. *Western Juniper in Eastern Oregon: Pacific Northwest Research Station General Technical Report PNW-GTR-464*, United States Department of Agriculture, Portland. 53 p, 5 maps.

Gillen, Denis F. 1996. *Verification of Roughness Coefficients for Streams in West-Central Florida.* U.S. Geological Survey Open-file Report 96-226. Retrieved June 28, 2005 from the Web site: http://il.water.usgs.gov/proj/nvalues/fl_webpage.html

Hall, LW., 1908. Letter to D.W. Murphy, Project Engineer, Klamath Falls, Oregon. November 10, 1908.

Harrington, Constance A. 2003. *The 1930 Survey of Forest Resources in Washington and Oregon: Pacific Northwest Research Station General Technical Report PNW-GTR-584,* United States Department of Agriculture, Portland. 123 p, including CD-ROM.

La Marche, J.. October 2004. Hydrologist, OWRD, Personal communication with Thomas Perry.

La Rue, E. C., 1922, Klamath River and its Utilization: USGS unpublished report.

Laut, A. C. 1910. Journal of Peter Skene Ogden; Snake Expedition (in four parts) In *The Quarterly of the Oregon Historical Society*, Vol. X, No. 4 ff, with editorial notes by T. C. Elliott.

Leonard, A.R., and A.B. Harris, 1974. *Ground water in selected areas in the Klamath Basin, Oregon*. Oregon State Engineer. Ground Water Report No. 21, 104 pp.

Newcomb, R.C., and D.H. Hart. 1958. *Preliminary report on the ground water resources of the Klamath River Basin, Oregon*: U.S. Geological Survey Open-File Report, 248 pp.

Overton, Scott S. 1977. A Strategy of Model Construction in Hall. C. A. S., and J. W. Day, eds., *Ecosystem Modeling in Theory and Practice: An Introduction with Case Histories*. Niwot: University Press of Colorado (1990 reprint). pp. 49-73.

Robbins, W. G., and D. W. Wolf. 1994. *Landscape and the Intermontane Northwest: An Environmental History*. General Technical Report PNW-GTR-319. USDA, Forest Service, Pacific Northwest Research Station. 40 pp incl. endleafs and cover.

Leiberg, John B. 1902. *Forest Conditions in the Northern Sierra Nevada, California*. U. S. Geological Survey Professional Paper No. 8, Washington. 194 pp.; 12 plates.

U.S. Army Corps of Engineers. April 2004. HEC-RAS River Analysis System, Version 3.1.2. *Hydraulic Reference Manual*. Chapter 3 Basic Data Requirements, Energy Loss Coefficients, page 3-12 to 3-16, Table 3-1 page 3-13

USDA, Soil Conservation Service. April 1985. *Soil Survey of Klamath County, Oregon, Southern Part.*

Maps and Drawings

Lippincott, J.B., D.W. Murphy, and T.H. Humphreys. 1905. Topographic and Irrigation Map, Upper and Lower Klamath Projects, California-Oregon 1905 (scale 1:48,000).

Lippincott, J.B. and T.H.Humphreys. 1905. Klamath Project, California-Oregon General Progress Map. Map No. 6092, April. (scale 1:250,000).

Reclamation. 1921. Contours showing reef at intake of Link River. Reclamation Drawing No. 12-OA-201-753.

Warren, R.T. 1928. Contour map of Keno reef between Keno Bridge and Keno Plant. COPCO Drawing No. G-4789. Reclamation Drawing Number 12-OA-201-572.

Other Maps Pertaining to Klamath River, Klamath Falls to Keno
COPCO Drawing Numbers

S(?)-4570, Upper and lower reefs at Keno: cross sections reach between Stations 17+00 and 25+00 1927 J.F. Partridge;

S(?)-4571, Lower reef at Keno: cross sections reach between Stations 53+00 and 66+00, 1927, J.F. Partridge;

S-4816, Profile and cross sections: Klamath River, Klamath Falls to Keno, 1926, USRS;

G-6287, Topography of area above Keno regulating Dam, 1942 G.D. Bowen;

F-5081, A Regulation dam site between Keno Bridge and Keno Plant. 1929. R.T. Warren;

F-5226, Properties along Klamath River, Klamath Falls to Keno. 1930. R.T. Warren;

F-6239, Klamath River-Lake Ewauna to Keno, no date (drawing no. assigned 1932);

PP-D-721, Klamath River: Depth of water at Whiteline Ranch. 1919. J.C. Boyle;

A-30416, Regulating Dam at Keno. 1929. Byllesby Eng.;

S-4569, Profile: Key developments along Link River between Upper Klamath Lake and Lake Ewuana, no date (drawing no. assigned 1927).

UKL: Newell, Robert, D., various years (1903-1919), *Annual Project History and O & M Report of the Klamath Project, California-Oregon.*

Contains graphs of Pre-Link River Dam Upper Klamath Lake elevations and discharge at Keno. Also, have quote that says "1917-18 was last year in which was operated in a state of nature—that is without control of any kind" (quote from note on calculation sheet to determine lake levels without dam and channel improvements on Link River by COPCO from UKL file in Reclamation Klamath Basin Area Office archive "vault").

All Areas (Water Supply Papers)

Klamath River Basin section of Water Supply Papers contained information on recorded flows, gage heights, locations of gages, changes to gages, types of gages, accuracy, and other miscellaneous information.

Arcement, George, J and Schneider, V.R.. 1989. *Guide for selecting Manning's roughness coefficients for natural channels and flood plains.* U.S. Geological Survey Water-Supply Paper # 2339. 39 p.

Barnes, Harry H., Jr. 1967. *Roughness Characteristics of Natural Channels.* U.S. Geological Survey Water Supply Paper # 1849. 213 pp.

Grover, Nathan, C., H.D. McGlashan and F.F. Henshaw. 1916. *Surface Water Supply of the United States 1913, Part X, Pacific Slope Basins in California.* USGS Water Supply Paper 361. Washington: Government Printing Office. 514 p.

Grover, Nathan, C., H.D. McGlashan, and F.F.Henshaw. 1917. *Surface Water Supply of the United States 1914, Part XI, Pacific Slope Basins in California*. USGS Water Supply Paper 391. Washington: Government Printing Office. 334 p.

Grover, Nathan, C., H.D. McGlashan, and F.F. Henshaw. 1918. *Surface Water Supply of the United States 1915, Part XI, Pacific Slope Basins in California.* USGS Water Supply Paper 411. Washington: Government Printing Office, 330 p.
(4085 feet references 4084 as incorrect in WSP 391, but datum in 411 is actually incorrect.)

Grover, Nathan, C., H.D. McGlashan, and F. F. Henshaw. 1918. *Surface Water Supply of the United States 1916, Part XI, Pacific Slope Basins in California*. USGS Water Supply Paper 441. Washington: Government Printing Office. 330 p.

Grover, Nathan, C., H.D.McGlashan, and F. F. Henshaw. 1920. *Surface Water Supply of the United States 1917, Part XI, Pacific Slope Basins in California*. USGS Water Supply Paper 461. Government Printing Office, Washington. 314 p.

Grover, Nathan, C., H.D. McGlashan, and F.F. Henshaw. 1921. *Surface Water Supply of the United States 1918, Part XI, Pacific Slope Basins in California*. USGS Water Supply Paper 481. Washington: Government Printing Office. 314 p.

Grover, Nathan, C., H.D. McGlashan, and F.F. Henshaw. 1923. *Surface Water Supply of the United States 1919 and 1920, Part XI, Pacific Slope Basins in California.* USGS Water Supply Paper 511. Washington: Government Printing Office. 456 pp.

Henshaw, F.F. and H.J. Dean. 1915. *Surface Water Supply of Oregon 1878-1910.* USGS WSP 370. Washington: Government Printing Office. 829 pp.

Lewis, John H. 1915. *Water Resources of the State of Oregon*. Bulletin No. 4, Salem, Oregon: State Printing Department, 353 p. (Klamath River Basin pp. 270-282).

Luper, Rhea. 1925. *Water Resources of the State of Oregon 1914-1924*. Bulletin No. 7. Salem, Oregon: State Printing Department. 265 pp. (Klamath River Basin pp. 189-207).

McGlashan, H.D. and H.J. Dean. 1913. *Surface Water Supply of the United States 1913, Part XI, Pacific Slope Basins in California*. USGS Water Supply Paper 300. Washington: Government Printing Office. 948 pp.

McGlashan, H.D. and G.C. Stevens. 1914. *Surface Water Supply of the United States 1912, Part XI, Pacific Slope Basins in California*. USGS Water Supply Paper 331. Washington: Government Printing Office. 442 pp.

02295420 Payne Creek near Bowling Green, Fla.

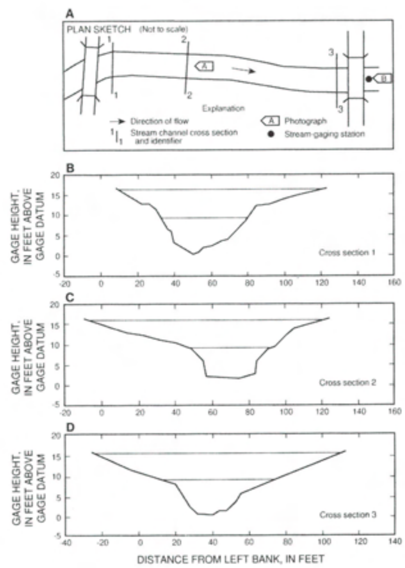

Figure 10. Payne Creek near Bowling Green. (A) plan sketch, (B) cross section 1, (C) cross section 2, and (D) cross section 3.

Figure 12. Payne Creek near Bowling Green. Photographs of channel looking (A) upstream from cross section 2 and (B) looking upstream from cross section 3.

Location.-- Lat 27°37'14", long 81°49'33", near Bowling Green, Florida.

Description of channel.-- d_{50} = 0 mm. d_{84} = 0 mm.

Date of observation	Average depth (ft)	Average surface width (ft)	Discharge (ft^3/s)	Average cross section area (ft^2)	Hydraulic radius (ft)	Mean velocity (ft/s)	Slope	Coefficient of roughness *n*
Sept. 10, 1988	---	---	1500.0	899.0	6.60	1.680	0.001030	0.104
Aug. 15, 1992	---	---	915.0	550.0	5.60	1.680	0.000810	0.081
Aug. 12, 1992	---	---	852.0	497.0	5.55	1.730	0.000700	0.071
Aug. 11, 1992	---	---	728.0	712.0	5.35	1.780	0.000670	0.064
Aug. 09, 1992	---	---	674.0	380.0	5.23	1.790	0.000710	0.065
June 30, 1992	---	---	607.0	336.0	4.99	1.820	0.000640	0.058

Sept. 05, 1992	---	---	539.0	298.0	4.77	1.820	0.000640	0.056
June 29, 1992	---	---	524.0	289.0	4.72	1.820	0.000630	0.055
Sept. 15, 1992	---	---	491.0	272.0	4.63	1.810	0.000660	0.056
June 26, 1992	---	---	460.0	256.0	4.56	1.800	0.000650	0.056

02295637 Peace River at Zolfo Springs, Fla.

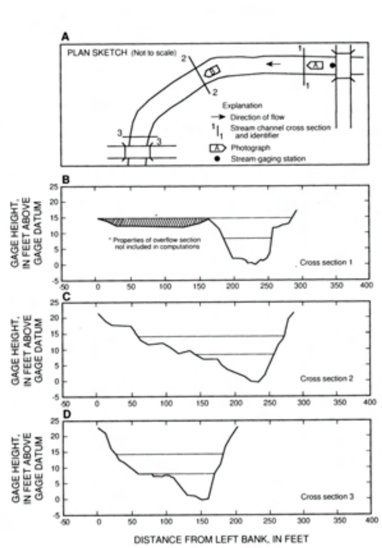

Figure 13. Peace River at Zolfo Springs. (A) plan sketch, (B) cross section 1, (C) cross section 2, (D) cross section 3.

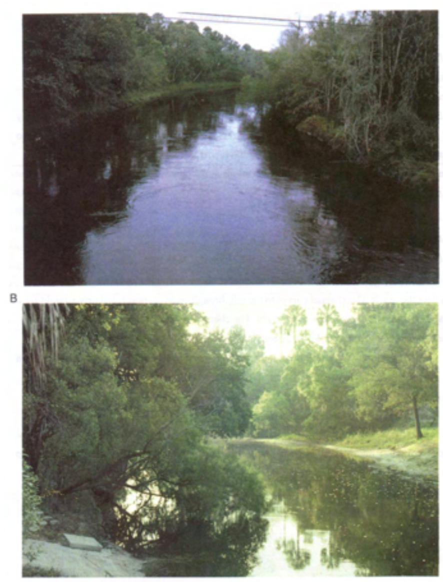

Figure 15. Peace River at Zolfo Springs. Photographs of channel looking (A) downstream from above cross section 1 and (B) looking downstream from above cross section 2.

Location.-- Lat 27°30'15", long 81°48'04", near Zolfo Springs, Florida.

Description of channel.-- d_{50} = 0 mm. d_{84} = 2 mm.

Date of observation	Average depth (ft)	Average surface width (ft)	Discharge (ft^3/s)	Average cross section area (ft^2)	Hydraulic radius (ft)	Mean velocity (ft/s)	Slope	Coefficient of roughness *n*
Aug. 12, 1992	---	---	3010.0	1310.0	7.12	2.390	0.000170	0.032
Sept. 05, 1992	---	---	2300.0	1100.0	6.26	2.170	0.000160	0.031

Aug. 31, 1992	---	---	1860.0	947.0	5.84	2.020	0.000140	0.029
June 30, 1992	---	---	1810.0	925.0	5.77	2.010	0.000130	0.029
Oct. 05, 1992	---	---	1760.0	904.0	5.71	2.000	0.000130	0.029
Sept. 17, 1992	---	---	1120.0	644.0	5.48	1.770	0.000100	0.029
Sept. 30, 1992	---	---	865.0	523.0	4.94	1.680	0.000080	0.026
Oct. 13, 1992	---	---	837.0	504.0	4.88	1.680	0.000090	0.029
Feb. 04, 1993	---	---	790.0	477.0	4.73	1.680	0.000110	0.030

02297155 Horse Creek near Myakka Head, Fla.

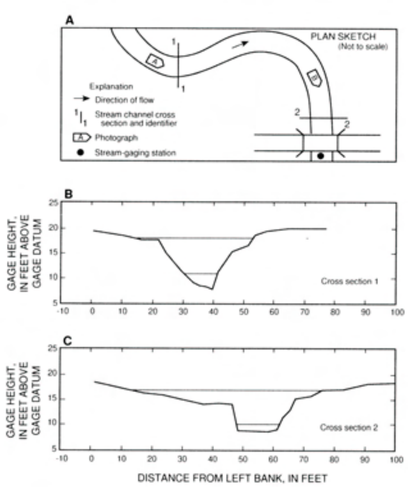

Figure 16. Horse Creek near Myakka Head. (A) plan sketch, (B) cross section 1, and (C) cross section 2.

Figure 18. Horse Creek near Myakka Head. Photographs of channel looking (A) downstream from above cross section 1 and (B) looking downstream from above cross section 2.

Location.-- Lat 27°29'13", long 82°01'25", near Myakka Head, Florida.

Description of channel.-- d_{50} = 0 mm. d_{84} = 0 mm.

Date of observation	Average depth (ft)	Average surface width (ft)	Discharge (ft^3/s)	Average cross section area (ft^2)	Hydraulic radius (ft)	Mean velocity (ft/s)	Slope	Coefficient of roughness *n*
Sept. 02, 1994	---	---	529.0	232.0	3.43	2.400	0.001600	0.060
Apr. 01, 1993	---	---	495.0	208.0	3.36	2.500	0.001470	0.054
Aug. 11, 1992	---	---	488.0	203.0	3.35	2.500	0.001600	0.056
Mar. 13, 1993	---	---	211.0	73.3	3.00	2.890	0.001630	0.044
Sept. 17, 1992	---	---	69.0	31.1	1.84	2.240	0.001500	0.039
Oct. 13, 1992	---	---	37.0	22.9	1.49	1.600	0.002270	0.058
Feb. 04, 1993	---	---	22.0	18.3	1.28	1.200	0.002410	0.071

02299737 South Creek near Vamo, Fla.

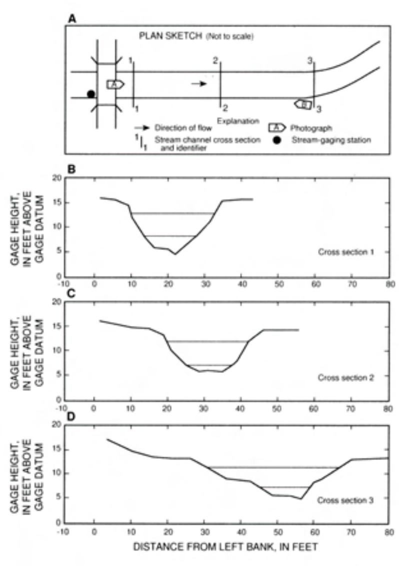

Figure 19. South Creek near Vamo. (A) plan sketch, (B) cross section 1, (C) cross section 2, and (D) cross section 3.

Figure 21. South Creek near Vamo. Photographs of channel looking (A) downstream from cross section 1 and (B) looking upstream from cross section 3.

Location.-- Lat 27°11'46", long 82°27'46", near Varno, Florida.

Description of channel.-- d_{50} = 0 mm. d_{84} = 0 mm.

Date of observation	Average depth (ft)	Average surface width (ft)	Discharge (ft^3/s)	Average cross section area (ft^2)	Hydraulic radius (ft)	Mean velocity (ft/s)	Slope	Coefficient of roughness *n*
Apr. 02, 1993	---	---	166.0	114.0	3.58	1.470	0.000380	0.047
Apr. 05, 1993	---	---	130.0	93.1	3.18	1.410	0.000360	0.043
Mar. 13, 1993	---	---	94.0	72.2	2.74	1.300	0.000330	0.040
Jan. 16, 1993	---	---	59.0	50.3	2.26	1.240	0.000410	0.043
Oct. 05, 1992	---	---	55.0	48.6	2.23	1.130	0.000380	0.043
Jan. 26, 1993	---	---	50.0	46.0	2.18	1.090	0.000410	0.045
Feb. 27, 1993	---	---	20.0	29.7	1.72	0.660	0.000360	0.059
Oct. 14, 1992	---	---	13.0	26.4	1.59	0.500	0.000520	0.090

02299861 Walker Creek near Sarasota, Fla.

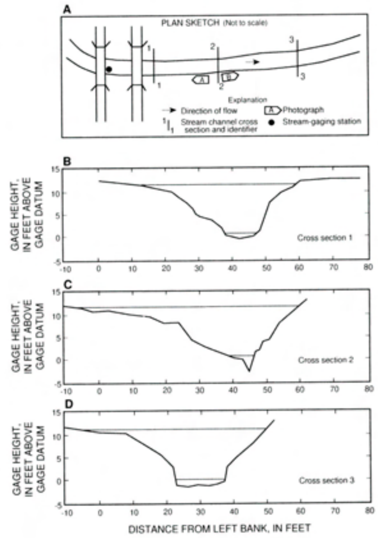

Figure 22. Walker Creek near Sarasota. (A) plan sketch, (B) cross section 1, (C) cross section 2, and (D) cross section 3.

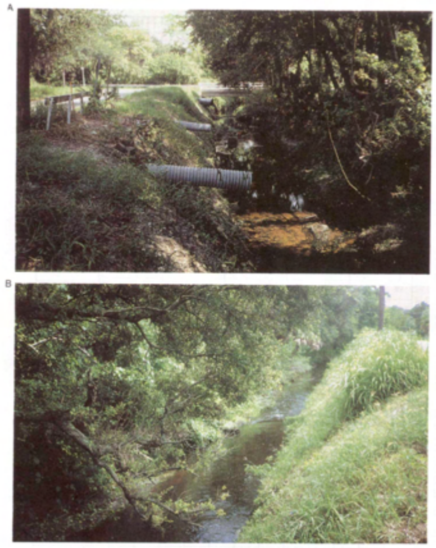

Figure 24. Walker Creek near Sarasota. Photographs of channel looking (A) upstream from cross section 2 and (B) looking downstream from cross section 2.

Location.-- Lat 27°22'03", long 82°32'40", near Sarasota, Florida.

Description of channel.-- d_{50} = 0 mm. d_{84} = 1 mm.

Date of observation	Average depth (ft)	Average surface width (ft)	Discharge (ft^3/s)	Average cross section area (ft^2)	Hydraulic radius (ft)	Mean velocity (ft/s)	Slope	Coefficient of roughness *n*
June 25, 1992	---	---	971.0	316.0	4.49	3.090	0.000950	0.042
July 23, 1992	---	---	438.0	166.0	4.14	2.570	0.000930	0.045
Aug. 07, 1992	---	---	398.0	157.0	4.40	2.290	0.000800	0.044
Apr. 01, 1993	---	---	312.0	131.0	3.79	2.400	0.000970	0.048
Apr. 01, 1993	---	---	278.0	121.0	3.63	2.320	0.000950	0.047
Jan. 15, 1993	---	---	242.0	107.0	3.40	2.290	0.000930	0.045
Jan. 15, 1993	---	---	217.0	103.0	3.33	2.140	0.001000	0.049
Jan. 14, 1993	---	---	141.0	73.8	2.74	1.940	0.001050	0.048
Sept. 27, 1994	---	---	19.0	25.0	1.53	0.800	0.001480	0.094

Feb. 29, 1992	---	---	13.0	26.7	1.60	0.530	0.001920	0.155
Oct. 14, 1992	---	---	9.4	20.1	1.33	0.540	0.001510	0.121
Mar. 12, 1993	---	---	4.8	17.8	1.22	0.320	0.001480	0.194
Nov. 16, 1992	---	---	4.6	16.3	1.15	0.330	0.001700	0.190
Dec. 14, 1992	---	---	3.9	16.2	1.15	0.280	0.001630	0.218

02300700 Bullfrog Creek near Wimauma, Fla.

Figure 27. Bullfrog Creek near Wimauma. Photographs of channel looking (A) downstream from above cross section 1, (B) looking downstream from cross section 3, and (C) looking upstream from cross section 5.

Figure 27. Bullfrog Creek near Wimauma. Photographs of channel looking (A) downstream from above cross section 1, (B) looking downstream from cross section 3, and (C) looking upstream from cross section 5--**Continued.**

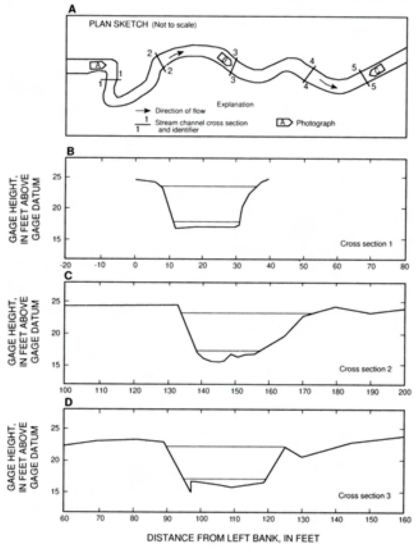

Figure 25. Bullfrog Creek near Wimauma. (A) plan sketch, (B) cross section 1, (C) cross section 2, (D) cross section 3, (E) cross section 4, and (F) cross section 5.

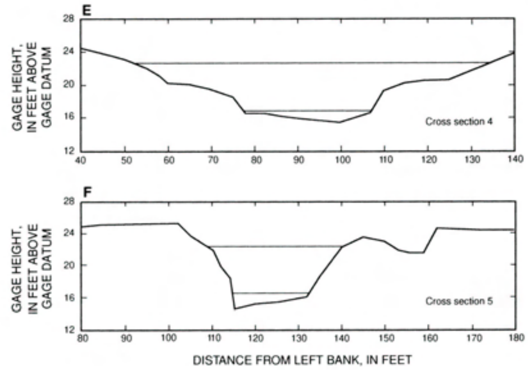

Figure 25. Bullfrog Creek near Wimauma. (A) plan sketch, (B) cross section 1, (C) cross section 2, (D) cross section 3, (E) cross section 4, and (F) cross section 5--**Continued.**

Location.-- Lat 27°47'30", long 82°21'08", near Wimauma, Florida.

Description of channel.-- d_{50} = 0 mm. d_{84} = 0 mm.

Date of observation	Average depth (ft)	Average surface width (ft)	Discharge (ft^3/s)	Average cross section area (ft^2)	Hydraulic radius (ft)	Mean velocity (ft/s)	Slope	Coefficient of roughness *n*
Mar. 13, 1993	---	---	356.0	211.0	4.00	1.820	0.000740	0.059
Apr. 16, 1993	---	---	264.0	163.0	3.79	1.710	0.000720	0.062
June 08, 1992	---	---	216.0	131.0	3.28	1.730	0.000820	0.058
Apr. 25, 1992	---	---	142.0	90.8	2.72	1.610	0.000630	0.055
Jan. 09, 1993	---	---	141.0	95.1	2.79	1.530	0.000800	0.057
June 16, 1992	---	---	19.0	21.0	0.90	0.930	0.000830	0.045
Nov. 16, 1992	---	---	11.0	14.7	0.67	0.780	0.000910	0.047

02301750   Delaney Creek near Tampa, Fla.

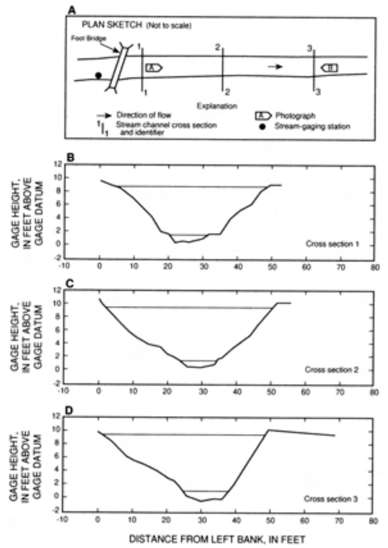

Figure 28. Delancy Creek near Tampa. (A) plan sketch, (B) cross section 1, (C) cross section 2, and (D) cross section 3.

Figure 30. Delaney Creek near Tampa. Photographs of channel looking (A) downstream from cross section 1 and (B) looking upstream from cross section 3.

Location.-- Lat 27°55'32", long 82°21'52", near Tampa, Florida.

Description of channel.-- d_{50} = 0 mm. d_{84} = 0 mm.

Date of observation	Average depth (ft)	Average surface width (ft)	Discharge (ft^3/s)	Average cross section area (ft^2)	Hydraulic radius (ft)	Mean velocity (ft/s)	Slope	Coefficient of roughness *n*
June 28, 1992	---	---	496.0	224.0	4.56	2.220	0.000570	0.045
Sept. 06, 1993	---	---	222.0	113.0	3.09	1.970	0.000300	0.028
Sept. 04, 1992	---	---	119.0	67.0	2.40	1.790	0.000290	0.024
Sept. 28, 1994	---	---	80.0	42.0	1.90	1.940	0.001000	0.035
Sept. 27, 1994	---	---	76.0	39.8	1.84	1.940	0.000900	0.032
Oct. 03, 1992	---	---	37.0	22.9	1.29	1.670	0.000910	0.029
Aug. 17, 1993	---	---	31.0	21.5	1.24	1.520	0.000950	0.031
Oct. 06, 1992	---	---	20.0	15.7	1.00	1.390	0.001050	0.032

Sept. 16, 1992	---	---	11.0	12.2	0.84	1.000	0.000870	0.035
Feb. 05, 1993	---	---	5.6	10.0	0.75	0.630	0.001030	0.055
Sept. 28, 1992	---	---	4.7	10.1	0.77	0.530	0.000910	0.063
Sept. 22, 1992	---	---	4.4	9.8	0.77	0.510	0.000900	0.065
Apr. 26, 1993	---	---	1.8	6.4	0.56	0.350	0.001020	0.080
Oct. 23, 1992	---	---	1.8	7.8	0.65	0.270	0.000980	0.112

02303205 Baker Creek at McIntosh Road near Antioch, Fla.

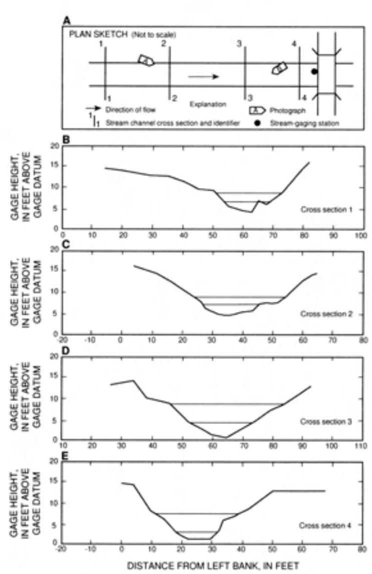

Figure 31. Baker Creek at McIntosh Road near Antioch. (A) plan sketch, (B) cross section 1, (C) cross section 2, (D) cross section 3, and (E) cross section 4.

Figure 33. Baker Creek at McIntosh Road near Antioch. Photographs of channel looking (A) downstream from cross section 2 and (B) looking upstream from cross section 4.

Location.-- Lat 28°01'41", long 82°14'41", near Antioch, Florida.

Description of channel.-- d_{50} = 0 mm. d_{84} = 0 mm.

Date of observation	Average depth (ft)	Average surface width (ft)	Discharge (ft^3/s)	Average cross section area (ft^2)	Hydraulic radius (ft)	Mean velocity (ft/s)	Slope	Coefficient of roughness *n*

Aug. 30, 1994	---	---	310.0	108.0	3.10	3.120	0.002230	0.051
Oct. 03, 1992	---	---	151.0	57.9	2.34	3.020	0.003240	0.058
Aug. 27, 1993	---	---	128.0	49.3	2.13	2.880	0.004760	0.066
Sept. 06, 1993	---	---	81.0	40.6	1.88	2.140	0.004270	0.095
Aug. 28, 1993	---	---	78.0	37.3	1.78	2.230	0.004150	0.088
Sept. 07, 1993	---	---	51.0	30.0	1.54	1.790	0.004240	0.108
Aug. 25, 1994	---	---	43.0	28.0	1.47	1.630	0.004510	0.118

02310000 Anclote River near Elfers, Fla.

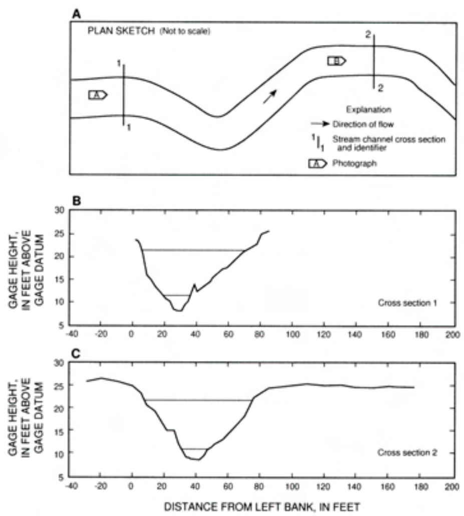

Figure 34. Anclote River near Elfers. (A) plan sketch, (B) cross section 1, and (C) cross section 2.

Figure 36. Anclote River near Elfers. Photographs of channel looking (A) downstream from cross section 1 and (B) looking downstream from cross section 2.

Location.-- Lat 28°12'50", long 82°40'00", near Elfers, Florida.

Description of channel.-- d_{50} = 0 mm. d_{84} = 0 mm.

Date of observation	Average depth (ft)	Average surface width (ft)	Discharge (ft^3/s)	Average cross section area (ft^2)	Hydraulic radius (ft)	Mean velocity (ft/s)	Slope	Coefficient of roughness *n*
Oct. 05, 1992	---	---	782.0	458.0	6.23	1.710	0.000520	0.066
Sept. 10, 1992	---	---	274.0	194.0	3.85	1.420	0.000720	0.068
Sept. 06, 1992	---	---	209.0	153.0	3.32	1.380	0.000880	0.070
Sept. 01, 1992	---	---	173.0	128.0	3.16	1.360	0.000680	0.060
Sept. 10, 1993	---	---	152.0	118.0	3.02	1.310	0.000840	0.069
Sept. 15, 1992	---	---	107.0	94.8	2.64	1.160	0.001240	0.086
Mar. 15, 1993	---	---	100.0	89.2	2.54	1.140	0.000740	0.066
Apr. 17, 1993	---	---	76.0	72.0	2.31	1.080	0.000780	0.067
Apr. 16, 1993	---	---	67.0	63.3	2.22	1.070	0.000660	0.060
Apr. 01, 1993	---	---	54.0	61.4	2.19	0.900	0.000720	0.075
Nov. 12, 1992	---	---	54.0	54.9	2.10	1.000	0.000880	0.072
Oct. 16, 1992	---	---	43.0	47.0	1.98	0.940	0.000880	0.074
Jan. 18, 1993	---	---	39.0	43.5	1.92	0.920	0.000780	0.069
Nov. 20, 1992	---	---	19.0	30.5	1.64	0.660	0.000860	0.093
Dec. 17, 1992	---	---	12.0	22.6	1.34	0.580	0.000640	0.081
Feb. 06, 1993	---	---	11.0	21.9	1.32	0.530	0.000880	0.098
Oct. 29, 1992	---	---	8.0	19.7	1.23	0.430	0.000840	0.122

02312720 Withlacoochee River at Wysong Dam at Carlson, Fla.

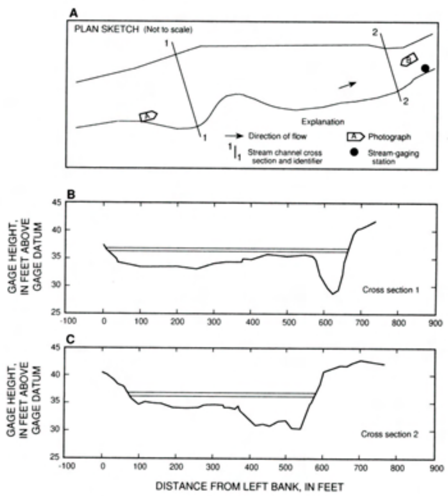

Figure 37. Withlacoochee River at Wysong Dam at Carlson. (A) plan sketch, (B) cross section 1, and (C) cross section 2.

Figure 39. Withlacoochee River at Wysong Dam at Carlson. Photographs of channel looking (A) downstream from cross section 1 and (B) looking upstream from cross section 2.

Location.-- Lat 28°49'23", long 82°11'00", near Carlson, Florida.

Description of channel.-- d_{50} = 0 mm. d_{84} = 0 mm.

Date of observation	Average depth (ft)	Average surface width (ft)	Discharge (ft^3/s)	Average cross section area (ft^2)	Hydraulic radius (ft)	Mean velocity (ft/s)	Slope	Coefficient of roughness *n*
Oct. 15, 1992	---	---	352.0	1890.0	3.22	0.190	0.000050	0.117
Sept. 28, 1993	---	---	332.0	1970.0	3.34	0.170	0.000070	0.157
Oct. 08, 1992	---	---	321.0	1830.0	3.12	0.180	0.000060	0.139
Mar. 17, 1993	---	---	313.0	1980.0	3.36	0.160	0.000050	0.148
Feb. 02, 1993	---	---	284.0	1720.0	2.96	0.170	0.000050	0.125
Aug. 02, 1993	---	---	282.0	1720.0	2.96	0.170	0.000030	0.097
Dec. 04, 1992	---	---	249.0	1680.0	2.89	0.150	0.000040	0.122

Nov. 19, 1992	---	---	232.0	1600.0	2.77	0.150	0.000020	0.086
Dec. 18, 1992	---	---	226.0	1490.0	2.76	0.150	0.000020	0.098
Aug. 26, 1993	---	---	200.0	1490.0	2.59	0.140	0.000050	0.146
June 03, 1993	---	---	169.0	1630.0	2.81	0.110	0.000030	0.161