United States Department of the Interior

BUREAU OF RECLAMATION
Klamath Basin Area Office
6600 Washburn Way
Klamath Falls, Oregon 97603

IN REPLY REFER TO:

DEC -5 2003

KO-150
ENV-1.10

Subject: Report Titled "Undepleted Natural Flow of the Upper Klamath River"

Dear Interested Parties:

The Bureau of Reclamation is pleased to provide the draft report titled *"Undepleted Natural Flow of the Upper Klamath River"*. The draft report and spreadsheet, with the calculations, are enclosed. This is a draft report and will be finalized after February 6, 2004.

Important Note: It is important that all recipients of this spreadsheet know they must assume responsibility for any changes they may make to the spreadsheet. Additionally, any changes must be documented with supporting data. This will allow anyone to track the origin of any altered versions, and not misrepresent the work of the original authors.

Sincerely,

Dave Sabo
Area Manager

Enclosures

TECHNICAL SERVICE CENTER
Denver, Colorado

UNDEPLETED NATURAL FLOW
OF THE
UPPER KLAMATH RIVER

Draft for Review

Prepared by
Water Supply, Use, and Conservation Group
Technical Service Center

U.S. Department of the Interior
Bureau of Reclamation

DECEMBER 4, 2003

UNITED STATES DEPARTMENT OF THE INTERIOR

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

BUREAU OF RECLAMATION

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.


Wocus Marsh. Photo and color by T. Perry.

Undepleted Natural Flow of the Upper Klamath River

Natural Inflow to, Natural Losses from, and Natural Outfall of Upper Klamath Lake to the Link River and of Lower Klamath Lake to the Klamath River at Keno

BOR Technical Service Center
Denver

Water Resources Services
Thomas Perry, Hydrologist
Ty Mull, Hydraulic Engineer
Amy Lieb, Hydrologist
Alan Harrison, Environmental Engineer

Concrete Dams and Waterways
Elizabeth Cohen, P.E., Hydraulic Engineer

BOR Klamath Area Office
Klamath Falls

John Rasmussen, Hydrologist
Jon Hicks, Water Conservation Specialist

This report was prepared for
Dave Sabo
Area Manager
Klamath Area Office
Klamath Falls, Oregon

December 5, 2003
Draft for Review

<u>Introduction</u> –

This report presents details of the aspects of the investigation and results in determination of the undepleted natural flow of the Klamath River. The area of study for the total scope of this investigation is the Klamath River basin above Keno, Oregon. Principal aspects this report are related to determination of the natural flow into Upper Klamath Lake, evaluation of the pre-development aspect of the lake and losses that would be incurred due to pre-development marshland and evaporation associated with the lake, and resulting natural outfall to the Link River at Klamath Falls. Principal aspects also include an evaluation of the pre-development aspect of the Lower Klamath Lake and losses that would have been incurred to the natural flow of the Klamath River at Keno due to pre-development marshland and evaporation associated with the lake. There evidently are no earlier studies that evaluate changes to the natural watershed above Upper Klamath Lake and adjust recorded streamflows to natural conditions based on changes in flow that are due to irrigation developments and reclamation of natural marshlands, or to changes in the natural system of Upper Klamath Lake and the consequent affect on the natural outfall to the Link River. The period of record considered in this investigation for reconstruction of natural flows is from 1949 to 2000, a period of 52 years. Methods used in evaluation of the natural flow for the Link River are described.

<u>Materials researched and reviewed</u> –

Supporting information used in the development of this study included a host of documents from archives of the Klamath Area Office, numerous Water Supply Papers regarding gaging records of the USGS, compact-disk databases containing digital records of gaged flow and lake stage records, and meteorological data. Many of the items reviewed were from newspaper articles or clipped from magazines. As such, much of this material was anecdotal consisting of information presented 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 Echos", the "Klamath Republican" and "The Evening Herald and News" newspapers, and sections of "50 Years on the Klamath" by JC Boyle. By reviewing a wide variety of anecdotal sources, an impression of pre-project conditions is gained which can be an adjunct to the empirical and scientific information gleaned from other sources. Past watershed and lake conditions were obtained through searches of the USBR Klamath Basin Area Office archives, the Shaw Historical Library at the Oregon Institute of Technology, the Klamath County Museum, USGS, Oregon Water Resources Department, and the internet.

Reviewed materials also included scientific reports, historical maps, letters, books, journals, and photographs. Generally, this historical information can be classified as empirical (and scientific) information consisting of reports of measurable data such as lake elevations, climate, land topography and ground cover (from surveyed maps), and river stages and discharge. For instance, historical topographic maps and previous studies were used to determine the extent of marshlands around the historical lake; construction drawings helped establish the pre-project structure of the reefs at the outlet of Upper Klamath Lake and in the Klamath River near Keno; and USBR records and USGS water supply papers provided pre-dam water surface elevations and discharges at key locations. Historical photographs are also considered empirical evidence of past conditions. Good examples are the several photographs of the Link River area prior to construction of the Link River Dam. Current conditions of the watershed were ascertained through information available from the USBR Klamath Basin Area Office such as water records, reports, maps and aerial photographs. Useful information regarding irrigation practices, land use and flow was also obtained from USGS and OWRD records. The information contained in the reviewed documents was used to as an aid in constructing, calibrating, and verifying the model. In addition to document reviews, reconnaissance trips were taken to verify current field conditions. A detailed examination of the field area was completed for the Wood River Valley in early August, 2002. At this time, the field area of the Sprague River was also examined.

Results of the assessment were accomplished using Excel, a sophisticated spreadsheet available in Microsoft's Office for Windows software package. The numerical model developed in Excel is really a detailed water budget of processes occurring in Upper and Lower Klamath Lakes. This spreadsheet, **ukl.lkl_simulation**, is clearly labeled and documented and is a separate part of this report.

<u>Numerical procedures and statistical methods</u> –

The evaluation of evapotranspiration from irrigated lands and marshlands, and evaporation from open water, required the use accepted procedures in the determination of these elements. Losses from irrigated fields and marshes and evaporation from the lakes must be quantified for a water budget accounting of processes.

Calculations and computations to obtain natural and cropland depletions through evapotranspiration –

- *Background*

One of the key pieces of a complete analysis of the flows in stream system is the evapotranspiration of the water used by the local vegetation and land uses. This is an output variable found in the water balance equation where inflows + local precipitation – evaporation and evapotranspiration = outflows. In this section the evapotranspiration (ET) component will be discussed and examined closely.

There are several ways of measuring the consumptive use of a plant directly by using, tanks, lysimeters, and plant tissue analysis. Since all of these scientific methods are time consuming and costly an estimated value is computed to determine the amount of water consumed by the plant community. There are several classifications of methods that can be used for estimating plant consumptive use. These are radiation (solar and heat balance), temperature, evaporation pan, and combination methods. The method that was chosen for this exercise was a temperature method or the SCS Blaney-Criddle method. This method was chosen because it is a monthly time step model and because the data availability limited the use to this model to monthly time steps.

The Blaney-Criddle model uses main driving variables of temperature and precipitation. Other models such as the Penman, FAO-Penman, and Penman-Monteith methods are much more accurate at estimating ET (Jensen, 1989), but the limited amount of climatic data did not allow for the use of these ET estimation methods. For the Blaney-Criddle procedure, temperature and precipitation data available from 1948 – 2002 was fairly complete for many stations scattered throughout the study area. Only a few years of most of the weather records had to be reconstructed using statistical methods.

The ET computer model used by the Bureau of Reclamation for monthly planning studies is XCONS. This program was developed in the late 1970's using FORTRAN and utilized the SCS Modified Blaney-Criddle ET equation. Later updates included adding a Visual Basic Graphical User Interface to give the user access for ease of use and output organization. The input files are in text format and spacing is critical when setting these files up. The output used in this exercise was imported into a Microsoft Excel Spreadsheet to compute the net ET in acre feet per month rather than in inches.

- *Data*

Weather data was obtained from the National Weather Service via the internet at the Western Region Climate Center and through various CD data bases produced by HydroSphere in Boulder Colorado. The following Meteorological stations were used to compile the needed average temperature and monthly precipitation data for this study. Rocky Point 3S, Fort Klamath 7SW, Chiloquin 7NW, Chiloquin 1E, Klamath Falls 2SSW, Merrill 2N, Sprague River 2 SE, Tulelake CA, Chemult, and Round Grove.

With the chosen model there are several other parameters that must be determined in order to complete the ET portion of the mass balance. These other parameters are cropping type, and the number of acres each crop or plant type encompasses. The cropping type can usually be found through statistical publications such as the USDA National Agricultural Statistics Service County Ag Statistics, or cropping can be evaluated by field verification. The amount of acreage covered by a certain plant type is generally more easily determined through remote sensing or the use of satellite imagery. Several sources of data were used in this study to determine land use and total acreage of plant and crop type. GIS coverages composed by Oregon Water Resources Department for use in water right databases and hydrology studies were provided for the Upper Klamath Basin tributaries. LandSAT satellite imagery was available for most all the area in the Upper and Lower Klamath Basins as well. A field evaluation was conducted in early August, 2002.

- *Upper Klamath Lake tributary watersheds*

From the collection of the data and the general topography and land use set up, a determination was made that the two tributaries to the Williamson River, Sprague River and Sycan River, as well as the Wood River would be handled as separate basins for the flow computations. These watersheds were then analyzed to determine the land use classification surrounding the rivers for an ET estimation calculation. The rivers all flowed into the Upper Klamath Lake and are the main inflow contributors to the lake. A GIS map of the region shows the major land classes and basin divisions that were used to calculate the ET for the four major river basins.

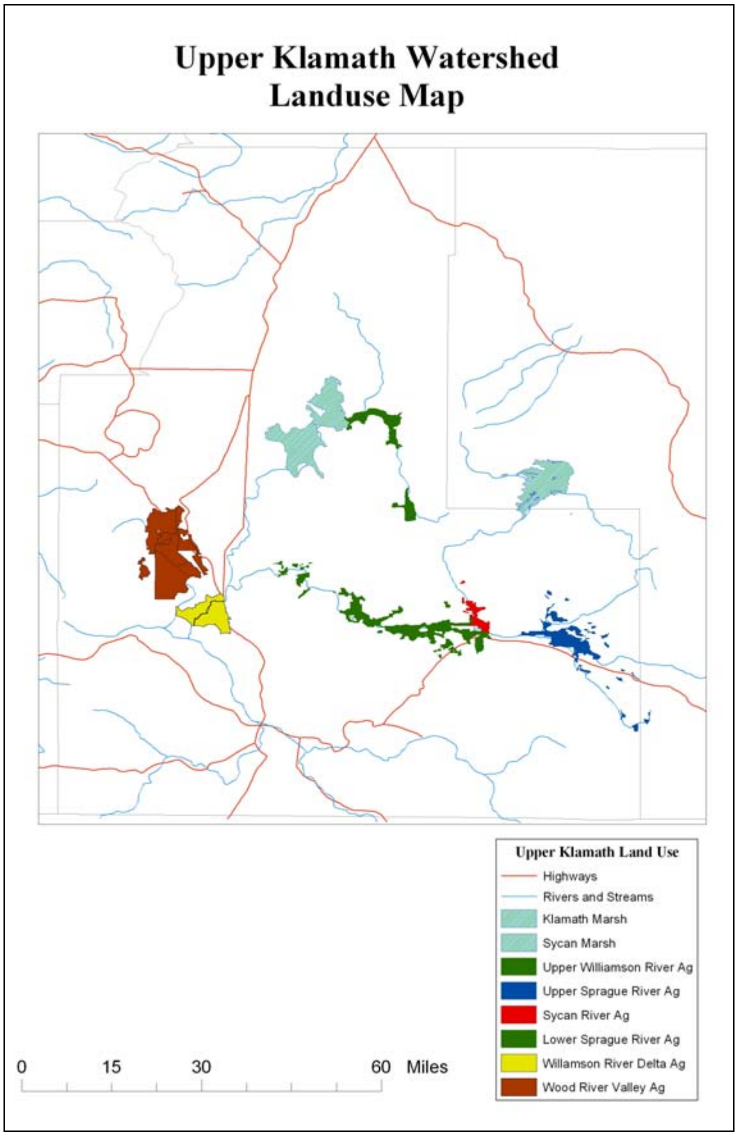


Figure 1 GIS coverage map of the Upper Klamath Lake watershed land use and land class.

The Sprague River Valley was divided into an upper and lower reach for further simplification of the calculations. The upper basin contained 17,132.2 acres of agricultural lands (primarily grass and alfalfa) and 8,224 acres of marshlands (primarily salt grass with some tules and rushes). The lower basin was comprised of 30,851 acres of agricultural lands. The marsh areas had been drained and converted to agricultural uses and no historical record existed of the historical natural vegetation on this reach. The three climatic stations that were used in the ET computations were Sprague River 2SE, Chiloquin 1E, and Round Grove.

The Sycan River is the major tributary to the Sprague River, having an estimated 4,806 acres of agricultural lands and 15,311 acres of riparian and marsh lands. The Sycan Marsh, which is at the headwaters of this river, encompasses 22,627 acres of land. Since the marsh has remained relatively untouched and is now a protected wildlife area, it was not considered in the flow reconstruction calculations because there is little net difference in the losses from those incurred under natural conditions. The Sprague River 2SE climatic station was used for the Sycan River ET calculations.

The next river basin in the upper system that was considered was the Main Williamson River. That basin contained 12,793 acres of irrigated pasture and currently 37,844.1 acres of marsh land. A historical estimate of marshland was made at 48,474.4 acres to account for reclamation of the land for agricultural and development purposes. There is a small diversion on the lower reaches of the river that services 6,000 acres of agricultural crops. The crop type mix was determined to be alfalfa, potatoes, sugar beets, grain, and pasture for the purposes of a separate water balance for that system. The Chemult and Chiloquin 1E gages were used for climatic data.

The last river basin in the system that was considered for the ET calculations was the Wood River. This valley is comprised of 30,000 acres of primarily irrigated pasture grasses. There are some riparian areas along the river and drains considered in the Upper Klamath Lake ET discussion.

- *Upper Klamath Lake ET*

The Upper Klamath Lake Marshland and Riparian areas were handled differently than the previous basin calculations regarding ET. Reconstructed precipitation histories were used for three incomplete climatic stations in the area. These stations were Chiloquin 7 NW near the fish hatchery, Fort Klamath 7SW near Cherry Creek and Rocky Point 3 S near Pelican Bay on the Upper Klamath Lake. Two complete meteorological stations were also utilized, Chiloquin 1 E and Klamath Falls 2SSW in the ET calculations. The ET was estimated using the Modified Blaney Criddle method as was performed for the above mentioned basins. Also provided were planimetered acreage values of the marshland and riparian areas in and around UKL. Three classification types of vegetation or marsh plants were determined for the ET calculations in and around the lake. These classes consisted of Lake Wetland Marsh, Emergent Lake Marsh, and Riparian Marsh. The Lake Wetland type consisted of vegetation that was completely submerged year round. These constitute bulrush, sedges, cattails, and tules. The Emergent Lake Marsh type was a vegetation type that is submerged only partially during the growing season. These are typically salt grasses and some other submerged root zone grasses. The Riparian areas consisted of a mix of rushes and tules as well as some riparian woody growth such as willow and cottonwood trees. For this exercise, an 80% rushes and 20% willow plant mix was used. The total acreages for the marsh area were then divided between the five met stations in the area. The following is a breakdown of the acreages and their respective climate stations.

1. Chiloquin 1 E HUC 18010202 contained 10,060.8 acres of Lake Wetland Marsh.
2. Chiloquin 7 NW HUC 18010201 contained 5632.0 Lake Wetland Marsh, 1350.4 acres of Emergent Lake Marsh, and 876.8 acres of Riparian Marsh.
3. Fort Klamath 7SW HUC 18010203 contained 9251.2 acres of Lake Wetland Marsh, 7616.0 Emergent Lake Marsh, and 108.8 acres of Riparian Marsh.
4. Klamath Falls 2SSW HUC 18010204 contained 11,033.6 Lake Wetland Marsh and 192.0 acres of Emergent Lake Marsh.
5. Rocky Point 3 S 18010203 contained 17,328.0 Lake Wetland Marsh and 467.2 Emergent Lake Marsh.

The total net consumptive use was then calculated using the XCONS results as given in inches, which were converted to acre-feet using the above acreage breakdowns.

- *Lower Klamath Lake and Marsh Area*

Lower Klamath Lake and Marsh areas were computed in much the same manner as that for the Upper Klamath Lake areas. The planimetered acreage of the historical marsh area was partitioned between two climatic stations. The Klamath Falls 2SSW and Merrill 2N data stations were used. Total marsh area was 55,842.1 acres with 37,208.4 acres in the Klamath Falls station area and 18,633.7 acres in the Merrill station area. The modified Blaney-Criddle procedure was used to compute an estimated consumptive use for these areas. Bulrush, sedges, cattails, and tules were used as the plant type for the consumptive use curves.

- Results

The output from XCONS is given in total inches per month and an annual total consumptive use in inches. The output gives total consumptive use, effective precipitation and net consumptive use, which is a difference in the total and the effective precipitation. The output was then imported into an Excel spreadsheet for ease of manipulation of the data. The data was separated by major land use type, Agricultural, Marshland, and Riparian areas. The net ET was then multiplied by the respective acreage of each land type and converted to feet for the final output table. See Table 1 for an example of the final output for Sycan River agricultural lands.

Table 1 Example output of ET data used in flow reconstruction process.

Net Consumptive Use in Acre-Feet
Total Acreage in Sycan 4806 Acres
Values in Acre-Feet
Climate Station Use: Sprague River

Station	State	Crop	Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sprague River	Oregon	Crop Mix	1948	0	0	0	0	396.50	1,551.27	1,365.71	1,188.15	1,031.96	70.76	0	0	5,604.33
Sprague River	Oregon	Crop Mix	1949	0	0	0	48.06	1,013.27	1,380.39	2,061.24	1,632.71	1,364.37	182.90	0	0	7,678.92
Sprague River	Oregon	Crop Mix	1950	0	0	0	0	508.64	1,289.61	2,079.93	2,017.19	0	162.87	0	0	6,059.57
Sprague River	Oregon	Crop Mix	1951	0	0	0	60.08	1,064.00	1,763.54	2,101.29	1,668.75	651.48	21.36	0	0	7,329.15
Sprague River	Oregon	Crop Mix	1952	0	0	0	154.86	488.61	1,206.84	2,172.05	1,527.24	1,233.54	443.22	0	0	7,225.02
Sprague River	Oregon	Crop Mix	1953	0	0	0	0	686.19	1,126.74	1,832.96	1,520.57	949.19	0	0	0	6,112.97
Sprague River	Oregon	Crop Mix	1954	0	0	0	254.99	720.90	1,246.89	1,943.76	1,355.03	853.07	33.38	0	0	6,409.34
Sprague River	Oregon	Crop Mix	1955	0	0	0	-	598.08	1,540.59	1,728.83	1,638.05	806.34	9.35	0	0	6,321.23
Sprague River	Oregon	Crop Mix	1956	0	0	0	85.44	682.19	947.85	2,148.02	1,561.95	467.25	277.68	0	0	6,173.04
Sprague River	Oregon	Crop Mix	1957	0	0	0	172.22	1,062.66	2,058.57	2,304.21	1,168.13	608.76	28.04	0	0	7,403.91
Sprague River	Oregon	Crop Mix	1958	0	0	0	66.75	516.65	1,282.94	2,097.29	1,830.29	914.48	499.29	0	0	7,209.00
Sprague River	Oregon	Crop Mix	1959	0	0	0	0	415.19	1,573.97	1,791.57	1,349.69	818.36	393.83	0	0	6,342.59
Sprague River	Oregon	Crop Mix	1960	0	0	0	0	658.16	1,585.98	2,293.53	1,455.15	955.86	0	0	0	6,950.01
Sprague River	Oregon	Crop Mix	1961	0	0	0	0	528.66	1,926.41	1,895.70	1,836.96	509.97	61.41	0	0	6,760.44
Sprague River	Oregon	Crop Mix	1962	0	0	0	0	456.57	1,464.50	1,607.34	1,250.90	0	164.21	0	0	4,943.51
Sprague River	Oregon	Crop Mix	1963	0	0	0	0	946.52	1,264.25	1,351.02	1,610.01	1,027.95	0	0	0	6,202.41
Sprague River	Oregon	Crop Mix	1964	0	0	0	0	188.24	1,161.45	2,053.23	1,623.36	938.51	80.10	0	0	6,046.22
Sprague River	Oregon	Crop Mix	1965	0	0	0	316.40	461.91	1,504.55	1,193.49	1,656.74	926.49	0	0	0	6,058.23
Sprague River	Oregon	Crop Mix	1966	0	0	0	184.23	937.17	958.53	1,376.39	1,612.68	1,109.39	0	0	0	6,177.05
Sprague River	Oregon	Crop Mix	1967	0	0	0	0	803.67	1,684.77	2,329.58	2,152.02	855.74	351.11	0	0	8,172.87
Sprague River	Oregon	Crop Mix	1968	0	0	0	0	861.08	1,623.36	1,727.49	1,623.36	505.97	62.75	0	0	6,404.00
Sprague River	Oregon	Crop Mix	1969	0	0	0	162.87	632.79	1,782.23	2,114.64	1,664.75	889.11	101.46	0	0	7,347.84
Sprague River	Oregon	Crop Mix	1970	0	0	0	0	957.20	1,903.71	2,253.48	1,843.64	387.15	0	0	0	7,343.84
Sprague River	Oregon	Crop Mix	1971	0	0	0	9.35	715.56	1,419.11	2,212.10	1,818.27	776.97	32.04	0	0	6,980.72
Sprague River	Oregon	Crop Mix	1972	0	0	0	0	853.07	1,770.21	2,107.97	1,695.45	469.92	186.90	0	0	7,084.85
Sprague River	Oregon	Crop Mix	1973	0	0	0	156.20	1,373.72	1,770.21	2,038.55	1,564.62	492.62	0	0	0	7,397.24
Sprague River	Oregon	Crop Mix	1974	0	0	0	0	723.57	1,873.01	1,890.36	1,899.71	1,170.80	196.25	0	0	7,753.68
Sprague River	Oregon	Crop Mix	1975	0	0	0	0	672.84	1,076.01	1,998.50	1,608.68	640.80	142.85	0	0	6,137.00
Sprague River	Oregon	Crop Mix	1976	0	0	0	25.37	1,066.67	1,092.03	1,393.74	1,435.13	1,249.56	399.17	0	0	6,662.99
Sprague River	Oregon	Crop Mix	1977	0	0	0	0	383.15	1,986.48	2,105.30	1,411.10	907.80	10.68	0	0	6,801.83
Sprague River	Oregon	Crop Mix	1978	0	0	0	0	479.27	1,441.80	1,922.40	1,469.84	977.22	347.10	0	0	6,636.29
Sprague River	Oregon	Crop Mix	1979	0	0	0	64.08	1,073.34	1,620.69	1,455.15	1,716.81	345.77	134.84	0	0	6,410.67
Sprague River	Oregon	Crop Mix	1980	0	0	0	150.86	631.46	1,145.43	2,188.07	1,520.57	857.07	256.32	0	0	6,749.76
Sprague River	Oregon	Crop Mix	1981	0	0	0	68.09	913.14	1,559.28	2,022.53	1,882.35	752.94	0	0	0	7,196.99
Sprague River	Oregon	Crop Mix	1982	0	0	0	0	603.42	1,525.91	1,982.48	1,560.62	588.74	48.06	0	0	6,306.54
Sprague River	Oregon	Crop Mix	1983	0	0	0	16.02	967.88	1,280.27	1,568.63	1,899.71	776.97	0	0	0	6,508.13
Sprague River	Oregon	Crop Mix	1984	0	0	0	0	736.92	1,451.15	1,620.69	1,806.26	560.70	0	0	0	6,177.05
Sprague River	Oregon	Crop Mix	1985	0	0	0	148.19	973.22	1,416.44	2,213.43	1,078.68	751.61	104.13	0	0	6,687.02
Sprague River	Oregon	Crop Mix	1986	0	0	0	0	991.91	2,105.30	1,922.40	1,589.99	648.81	236.30	0	0	7,493.36
Sprague River	Oregon	Crop Mix	1987	0	0	0	423.20	877.10	1,509.89	1,831.62	1,800.92	1,233.54	587.40	0	0	8,263.65
Sprague River	Oregon	Crop Mix	1988	0	0	0	132.17	683.52	1,656.74	2,277.51	1,716.81	1,110.72	0	0	0	7,576.13
Sprague River	Oregon	Crop Mix	1989	0	0	0	401.84	1,023.95	1,698.12	1,752.86	1,140.09	548.69	218.94	0	0	6,787.14
Sprague River	Oregon	Crop Mix	1990	0	0	0	86.78	722.24	1,224.20	1,885.02	1,549.94	1,126.74	347.10	0	0	6,946.01
Sprague River	Oregon	Crop Mix	1991	0	0	0	0	536.67	1,230.87	2,356.28	2,031.87	1,220.19	299.04	0	0	7,674.92
Sprague River	Oregon	Crop Mix	1992	0	0	0	308.39	1,137.42	1,734.17	2,050.56	1,943.76	451.23	263.00	0	0	7,885.85
Sprague River	Oregon	Crop Mix	1993	0	0	0	1.34	951.86	1,325.66	1,297.62	1,451.15	861.08	295.04	0	0	6,185.06
Sprague River	Oregon	Crop Mix	1994	0	0	0	156.20	1,054.65	1,094.70	2,228.12	1,623.36	1,141.43	10.68	0	0	7,309.13
Sprague River	Oregon	Crop Mix	1995	0	0	0	102.80	558.03	1,106.72	1,764.87	1,436.46	1,082.69	89.45	0	0	6,141.00
Sprague River	Oregon	Crop Mix	1996	0	0	0	0	479.27	1,419.11	2,117.31	1,476.51	690.20	10.68	0	0	6,190.40
Sprague River	Oregon	Crop Mix	1997	0	0	0	29.37	1,007.93	939.84	1,636.71	1,352.36	743.60	21.36	0	0	5,731.16
Sprague River	Oregon	Crop Mix	1998	0	0	0	0	283.02	1,108.05	2,132.00	1,557.95	1,043.97	0	0	0	6,124.98
Sprague River	Oregon	Crop Mix	1999	0	0	0	0	562.04	1,316.31	1,379.06	1,738.17	784.98	332.42	0	0	6,114.30
Sprague River	Oregon	Crop Mix	2000	0	0	0	472.59	1,189.49	1,703.46	2,293.53	1,771.55	760.95	196.25	0	0	8,389.14
Sprague River	Oregon	Crop Mix	2001	0	0	0	52.07	1,214.85	1,221.53	1,975.80	1,724.82	1,125.41	0	0	0	7,314.47

After computing the net ET for several of the climatic stations, plots were created to observe the plant water use curve for verification of accuracy on the established crop curve. Several stations did not represent the appropriate crop curve for the specific river basin and had to be discarded or used to calibrate and reconstruct other climatic stations. The plot shown in Figure 2 is an example of the crop curves that were created.

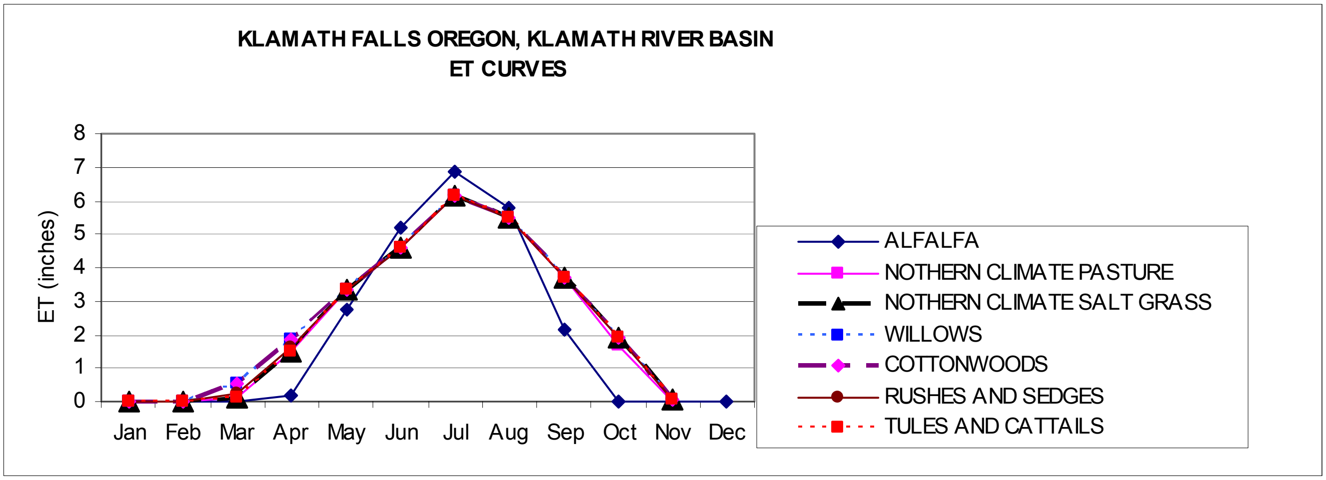


Figure 2 Plot of various crops ET curves for the Klamath Falls 7SSW station.

The results of the ET calculations were compared against the Oregon Crop Water Use and Irrigation Requirements guide for validation (Cuenca 128 – 130). This guide is the best available source for comparing measured crop ET values to estimations. The estimations were then adjusted by increasing or decreasing the growing season length for best estimation.

Evaporation Calculations –

No water balance calculation is complete without estimates or measurements of evaporative losses from the system in question. Unfortunately, there are few reservoir systems for which long-term evaporation measurements are available (Linsley, et al, 1982), particularly when considering pre-development conditions. Given these constraints, an empirical or energy balance method of estimating evapotranspiration in the Klamath system must be developed.

- *Energy Balance Method*

The Penman Equation is one of the most widely used and accepted methods for calculating potential evaporative losses from a free water surface. Penman is also considered by many to be the recommended method when appropriate data are available (FutureWater, 2003, Snyder, 2000). Estimations of potential evaporation are calculated by consideration of the requirements to balance the energy budget at the water surface (Penmanetc, 2003).

The Penman Equation requires a large amount of measured data, including net radiation exchange at the water surface, energy advected to the water body, minimum and maximum temperature, relative humidity, and wind speed (Penmanetc, 2003). Needless to say, the required data for proper calculation of Penman evaporation is not readily available in the Klamath basin, nor is it available for the period of record of this study.

The Bureau of Reclamation has recently begun collecting the necessary data to calculated a Penman derivative, the Kimberly-Penman, through the AgriMet station in Klamath Falls. These data are available for the period of March 31, 1999 through the present (AgriMet, 2003).

- *Empirical Method*

The Hargreaves' Equation is an empirical formula derived to allow the estimation of potential evaporation based solely on air temperature, and knowledge of the latitude of the site (Penmanetc, 2003, Snyder, 2000). Even though the Hargreaves' Equation was originally developed to estimate evaporation from agricultural systems, reasonable estimates of potential evaporative losses can be obtained by considering monthly totals (Penmanetc, 2003).

- *Procedure Used to Calculate Potential Evaporation*

The first attempt to determine potential evaporation was a correlation of existing Kimberly-Penman evaporation from the AgriMet station to readily available maximum, minimum, and average air temperature readings for the same period. This exercise resulted in only marginal success with R^2 values ranging from 0.61 to 0.79.

Because of the lack of appropriate data necessary to calculate evaporation using the Penman Equation, and the references obtained indicating that the Hargreaves' Equation is capable of producing reasonable results (Penmanetc, 2003, Hargreaves', 2003, FutureWater, 2003), the Hargreaves' Equation was chosen for this study.

The Hargreaves' Equation takes the form:

$$E = 0.0023 S_0 (T + 17.8)\sqrt{\delta}$$

Where:

E = Potential evaporation (mm/day)
T = Temperature (°C)

δ_T = The difference between mean monthly maximum and minimum temperatures (°C)
S_0 = Extraterrestrial radiation given by:

$$S_0 = 15.392 d_r (\omega \sin\phi \sin\gamma + \cos\phi \cos\gamma \sin\omega)$$

Where:
ϕ = Site latitude
ω_s = Sunset hour angle (radians) given by:

$$\omega = \arccos(-\tan\phi \tan\gamma)$$

γ = Solar declination on julian day J given by:

$$\gamma = 0.4093 \sin\left(\frac{2\pi}{365} J - 1.405\right)$$

d_r = Relative distance from the earth to the sun for julian day J given by:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right)$$

The temperature and station location data used to calculate the Hargreaves' potential evaporation came from the 2002 Hydrodata CD.

Evaporation for six stations: Klamath Falls, Chemult, Chiloquin, Merrill, Sprague River, and Tule Lake, was calculated. Two stations were used to get a complete period of record for the Klamath Falls area, with the primary data coming from the 2SSW station. Missing data was supplemented from the Ag. station when available.

The daily Hargreaves' evaporation estimates were compared with the Kimberly-Penman evaporation data obtained for the Bureau of Reclamation AgriMet station for the period March 31, 1999 through December 1, 2001. The data were correlated with an r^2 of 0.92. The Hargreaves' Equation generally gave a lower estimate than the Kimberly-Penman calculation. Based on the correlation of Hargreaves' and Kimberly-Penman evaporation calculations, an adjusted Hargreaves' estimate was also developed.

Time series synthesis –

Restoration of gaged monthly flow histories to longer-term natural flow histories and the determination of inflows from ungaged watersheds must consider development of complete records for the period of interest based on recorded information that is available. Within the study area, gaging station and meteorological records must be examined to determine if these records are complete, and if there is sufficient information in records from nearby stations that may be useable for the restoration of records used in the assessment. Limited, incomplete records provide a time-series history that is only partially representative of conditions within the study area. Therefore, to assess natural flows and formulate considerations for an assessment of natural water bodies, a time-series history for each related representative record must be developed based on a reconstruction that is representative and that covers the period of interest. In other words, the reconstruction must be consistent with conditions existing within the vicinity of the station associated with the record being reconstructed.

These considerations are important for two reasons. Net consumptive uses determined for irrigated crops and natural marshlands require a complete meteorological history of monthly precipitation and average temperature for the period of interest. The natural inflow to the water body cannot be determined if streamflow cannot be restored to natural flow by adjustments due to these consumptive uses. Further, many of the natural flows have been determined at inflow locations to stream reaches that must be treated in a water-budget to evaluate the inflow from the stream reaching the water body. Therefore, incomplete records, whether for meteorologic stations or stream gaging stations, must be reconstructed to provide a continuous time-series of monthly values for the period of interest.

To begin the reconstruction process, all supporting stream-gaging records must be reconciled as natural flow records. Such records will show streamflow as equivalent gaged natural flow. This is essentially measured flow at the gage that is unaltered by upstream diversions, reservoir storage, or other uses and longer-term temporal changes in watershed conditions that may adversely affect natural streamflow. Some records are already in this condition. However, records having demonstrated affects from upstream uses were adjusted to remove the alterations to the gaged flow caused by such uses. In many cases, upstream uses are inconsequential to restoration and the gaged flow may be considered equivalent to natural flow. This restoration process is necessary to remove alterations masking natural climatic variability that would be evident in these principally supporting stream-gaging records. Records possessing clear and essentially unmasked natural variations are generally easy to compare and cross-correlate, especially when such records may be of insufficient length to otherwise provide meaningful results, and must therefore be statistically restored to a longer period of record. Such records are also required to evaluate the impact of the alterations, especially in natural flow assessments.

Meteorological records, however, have different requirements. A meteorological time series for a station at one location must be reconciled to a record for a station existing at that location. Because a particular data record may be for a station that has been relocated, usually to a nearby location less than three miles away, records must be examined to determine if the new record is continuous with the older record or if there is a break due to slightly different climatic conditions existing at the new location. Records that are useable show no breaks and are continuous. Records that do not meet these criteria must be reconstructed because some of the data for one or more of the previous locations will not be useable.

In the correlation process, two types of records are considered. Primary records are time-series histories that are considered independent in forming the basis of the correlation. Such records are not considered the subject of the reconstruction, but are used in forming the basis for the reconstruction. Time-series histories that form the subject of the analysis, but are of insufficient length or have missing values, are considered as secondary records and must therefore be restored. The common base-period for the reconstruction must be of sufficient length that meaningful results may be derived from analysis of the records. For a collection of shorter-term records being used in the correlation process, the length of this common base-period is usually defined as beginning with the date of the earliest record starting the period in question, and finishing with the ending date of the latest record terminating the period in question. A least-squares correlation procedure is used to derive the values that are absent within this established, inclusive, common base-period of record.

For this analysis to be successful, three criteria must generally be satisfied. Although previously stated somewhat differently, the basic premise of these criteria is still the same. First, the primary record used to restore missing values in a secondary record must have unaltered seasonal characteristics or monthly variation characteristics that are similar to the secondary record being restored. Unaltered seasonal characteristics, as indicated previously, are indicative of the regional climatic factors. Second, concurrence of these records must provide sufficient values to demonstrate meaningful results in the use of correlation analysis. If concurrence is insufficient, correlation results can become deceptive or difficult to interpret. Third, the primary records that are being used must be for stations in the geographic vicinity of the secondary records being restored. As indicated previously, this is necessary to maintain regional consistency in relation to climatic factors that affect precipitation and drive streamflow.

Correlation analysis is a statistical procedure by which values missing in a secondary record, **B**, may be estimated through correlation of this secondary record with a primary record, **A**. This method uses a least squares, or similar, procedure to fit a straight, or curved, line through the [x,y] scatter plot evidenced by corresponding **[A,B]** values within the two data sets. The primary data set, **A**, is taken as the independent (x-axis) variable while the secondary data set, **B**, is taken as the dependent (y-axis) variable. Evidence of a good correlation between corresponding values in **A** and **B** is indicated when the points that comprise the scatter plot may be closely approximated by, or lie close to, the line fitted to the scatter plot. For records that are time associated, missing values in **B** are then computed from the equation for the line by using the appropriate time associated value given in **A**. The explained variation in relating the secondary data set, **B**, with the variation in the primary data set, **A**, is usually very good when the correlation relationship is good. This means that the variability in **B**, for instance, or difference across the range from high to low values in **B**, is explained well when the correlation of **B** with **A** is good. Generally, however, when the correlation relationship declines, the explained variation declines. When there is no correlation between the data sets, the least-squares line of relationship between **A** and **B** has simply one value equal to the average noted for the data group in **B** forming the scatter plot with the concurrent data group in **A**. Therefore, as the explained variability declines, values missing in **B** that are reconstructed using a least-squares procedure, tend toward the average for the values originally existing in **B** that are, as a data group, concurrent with corresponding values in **A**. This loss of information regarding explained variability is particularly important in the assessment of extreme values, or those occurring at the high and low ends of the range in reconstructed data for **B**. Hence, with adequate data, the variation explained through the use of correlation analysis is directly related to demonstration of meaningful results in the analysis of the records.

Completion of the reconstruction process is relatively straightforward. A pool of available primary records is statistically compared in the correlation with the secondary record being reconstructed and the explained variation being recovered is noted in a matrix for each month with each primary record. This explained variation is used as a guide, but not as a rule, in selecting the best monthly correlations that will be assembled into the final record. Because this analysis was carried out on a calendar month basis, the best correlation for each given month could be chosen from the cadre of correlation results that were available from the pool of useable records. In addition, there are special considerations that must be examined in completing the correlation analysis. Real values that cannot be negative must be derived from a line forced through the origin. Where loss of information in the correlation is noted to significantly degrade recovered variability, the least-squares procedure was not used. In such cases, depending on the evidence of curvature noted in the scatter plot, any one of several line-fitting procedures may be used based on the recovery of representative variability that is estimated to exist within the record being reconstructed. As such, this recovered variability is unexplained. For the generalized procedure, the line of minimum absolute deviation (Zebrowski, 1979) was noted, as a general rule, to give results equivalent to the least-squares procedure when the explained variation being recovered was greater than about 70 percent, or would otherwise provide reasonable recovery of estimated representative variability when the explained variability was less than 70 percent. Either procedure was easily modified to accommodate evidenced curvature in the correlation relationship. The procedures being used were essentially the same as those demonstrated graphically by Ried, Carroon, and Pyper (1969). General methods used are well documented in Pollard (1977), Lapin (1983), in addition to Zebrowski ((1979).

- *Sources of records being used*

Stream gaging-station records are available from the water-supply papers published by the U. S. Geological Survey, or are accessible from comprehensive databases maintained by the U. S. Geological Survey, the Oregon Water Resources Department, or on compact disks as published by Hydrosphere. Streamflow records of principal interest included the gaged record for Rogue River above Prospect and for South Umpqua River at Tiller. In addition, the gaged record for Sprague River near Chiloquin, and for Williamson River below Sprague River near Chiloquin, were primary records that were complete for the period of interest. Other records were supplied by the U. S. Forest Service for streams along the eastern flank of the Cascades.

Comprehensive databases providing precipitation records are available from the National Oceanographic and Atmospheric Administration and from compact disc records of U. S. Weather Bureau weather-data summaries that are published by Hydrosphere. In addition, long-term records were available from the Hydroclimatic Data Network. The meteorological records of principal interest essentially included Klamath Falls, Chiloquin, Sprague River, and Round Grove. The Klamath Falls precipitation record comprises a sequence documenting a continuous and nearly complete history from about 1906 to 2001. These records (except Chiloquin) were carefully examined and missing monthly values were researched, and recovered from Weather Bureau monthly summaries showing values for missing entries that had been previously estimated and published. Remaining missing values in these precipitation records were then statistically reconstructed, if required, by correlation with the record of one, or more, nearby precipitation stations.

- *Reconstruction of flows from unaged watersheds*

The determination of the flow history for an ungaged watershed is, in many cases, determined by transference of a flow history from a gaged watershed. The technique used to synthesize the streamflow history attributable to an ungaged watershed is termed, herein, the watershed characteristics method. The basis for using this method depends upon having, or being able to develop, an adequate and representative series of gaged-discharge histories from which to make the assessment. Comparable flow histories developed from these gaged-discharge histories may then be derived for several representative subwatersheds, known as type-watersheds, that are in the vicinity of, or within, the study area. Each of these type-watersheds has characteristics that are applicable to nearby ungaged watersheds in the study area. Therefore, if an adequate gaged-discharge history is available, the discharge for the same historical period may be determined for a particular ungaged watershed in the study area. This is accomplished by using the ratios of the respective type-watershed characteristics to ungaged-watershed characteristics so that the gaged-watershed history may be adjusted to that of the desired ungaged watershed. These characteristics are defined by watershed cover, watershed area, average annual precipitation, and the elevation-dependent seasonal distribution of flow variability that is evidenced by the type-watershed. Most of the gaging records for these type-watersheds, however, are incomplete and must be reconstructed for most of the full period of interest.

Completion of this process requires at least three elements to be satisfied. First, the comparable gaged-flow histories must be derivable for type-watersheds having discharge characteristics that are similar to those of the ungaged watersheds of interest. Second, the comparable gaged-flow histories of these type-watersheds must be for a concurrent time period of sufficient length that a reasonable sample in monthly flow variability may be obtained. Transference of these gaged-history components to ungaged watersheds then provides a consistent basis from which the variability in discharge of the ungaged watershed may be determined. Third, because regional climatic variability will adversely affect the analysis, the gaged watersheds to be used in this process must be in the vicinity of the watersheds being evaluated in the study area. For the transference process to work properly, the regional distribution of seasonal precipitation, and long-term climatic variability in precipitation and streamflow, must be consistent within the area for which the process is being applied. Use of nearby gaging-station histories that show climatic consistency allows regional climatic variability to be eliminated as an adverse variable in the analysis. Extraneous factors affecting watershed discharge that may be different in a gaged watershed than in an ungaged watershed of interest, may then be accommodated to allow an estimate of streamflow in the ungaged watershed.

For many of the watersheds examined in this study, use of the watershed-characteristics method was not directly possible. However, for the various methods used, the elements, above, defining the applied criteria, were the same. For many of these watersheds, records of gaged flow were useful more indirectly in reconstructing a longer-term flow history, than by direct transference of a characteristics-rescaled flow history from an adjacent watershed. For these streams, correlation analysis was the primary tool used in developing the flow histories. Essentially, statistically reconstructed records of estimated gaged flows for Cherry Creek, Sevenmile Creek, and Annie Creek, among others, form the bases of reconstructed flow histories for the assessment of streamflows within some of the other ungaged watersheds in the Wood River Valley portion of the study area. These records, and the derived discharges from all ungaged watersheds, were evaluated based on monthly total flow in acre-feet.

- *Veracity of reconstructed natural flow histories*

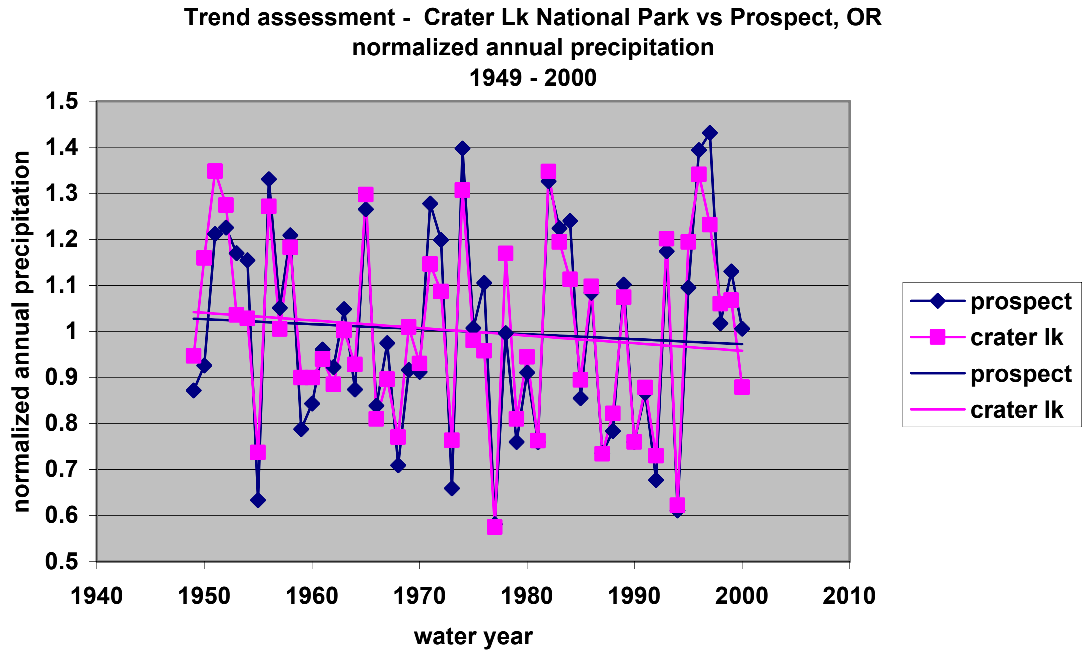
Within a region having consistent climatic factors that drive precipitation and streamflow, reconstructed, derived, and measured natural flow records should all be comparable. This comparability can be demonstrated primarily for longer-term precipitation histories within the region because precipitation is driven by a process that is naturally occurring. Further, precipitation is the principal climatic factor driving streamflow. Therefore, trends evidenced in natural flow records should show the same trends as those evidenced in precipitation records.

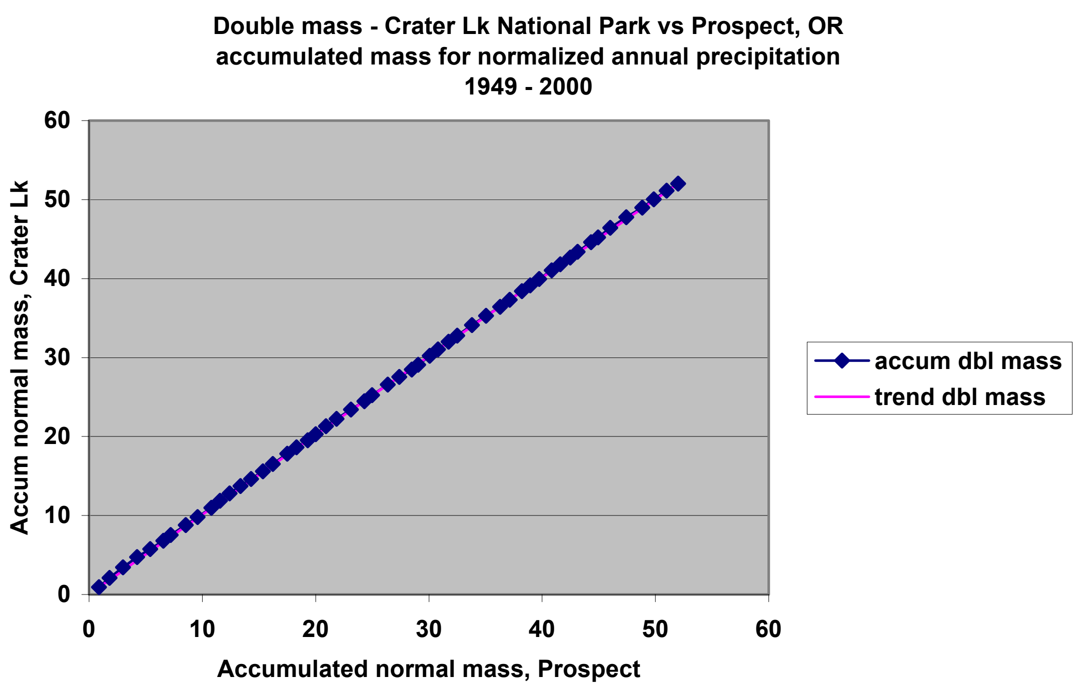
Trend analysis can easily demonstrate the consistency between records of each type. The methods used are related to a comparison of real trend and of the mass accumulation that occurs in the normalized annual time series. Real trend is an indication given by the equivalent trapezoid for the time series over the period of interest. The indication is valid only across the time interval being examined. The slope of the trend, determined in this way, is very sensitive to changes evidenced across the time interval and will readily show any consistency, or inconsistency, in the comparison of two similar records. For the determined period of interest, this comparison may be shown as either the linear trend expressed in each of the normalized annual records, or as the concurrent double-mass curve. Inconsistent trends will be evidenced immediately in the expressed deviations of the double-mass curve. The nature of this inconsistency is also easily seen, or evident, in the expression of slope for each of the trends shown for the normalized annual time series.

To begin the analysis, suitable stations must be chosen in forming the basis for the comparison. A suitable station is one that has a flow record, or precipitation record, for a gage that is in the vicinity of the gages, or locations, for which the restored natural flow records are being challenged. Such stations are therefore termed *basis stations*. However, given the limitations presented to this study, only one suitable flow record is available to establish this comparison basis. Therefore, this record must itself be checked to verify the natural flow consistency evidenced in the record. Gaged watersheds that have been subjected to progressive development will have flow histories showing an uncharacteristic deviation in mass accumulation when compared with the flow history of a nearby natural flow station. Given the specific conditions for suitability within this regional comparison of gaged flow histories for watersheds having natural flow, the records will show the same trend as that evidenced in precipitation histories covering the same period of interest for stations within the same region. Any loss of fidelity in the trend will be an immediate indication of unaccounted changes in watershed condition or inconsistencies in the natural flow derivation. Reconstruction of the natural flow history for a stream may be considered as effective and representative *if the trend for the period of interest shows no evident changes from that expected for a watershed under natural conditions*.

- *The basis stations for comparison of restored natural flow*

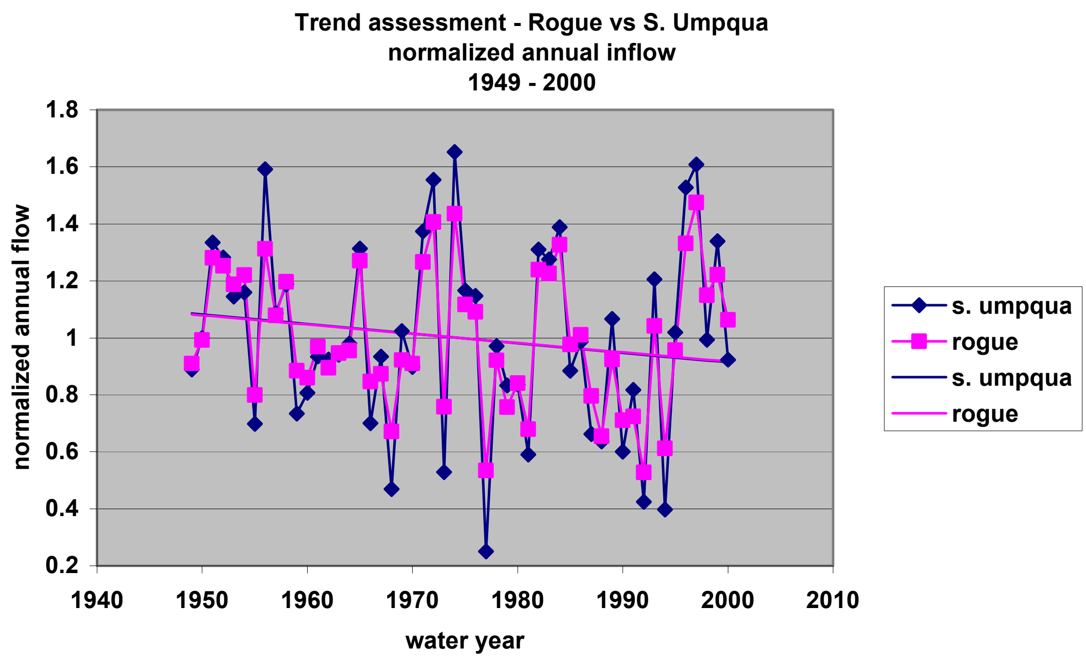
To establish regional consistency in climatic factors, an assessment of trend evidenced for precipitation at Prospect, and at Crater Lake, was completed. Precipitation histories for each of these stations were examined and several missing monthly values reconstructed so that a complete precipitation history was available for each station. The comparisons are for normalized values of annual precipitation. Similar comparisons were also completed for each month, and these were checked to determine the representative nature of the results. Both records are stable as they are each from data collection platforms maintained at fixed locations. Results of the annual analysis for these time series are shown above. Of note is the indication that annual total precipitation shows a slightly greater declining trend on the east side of the

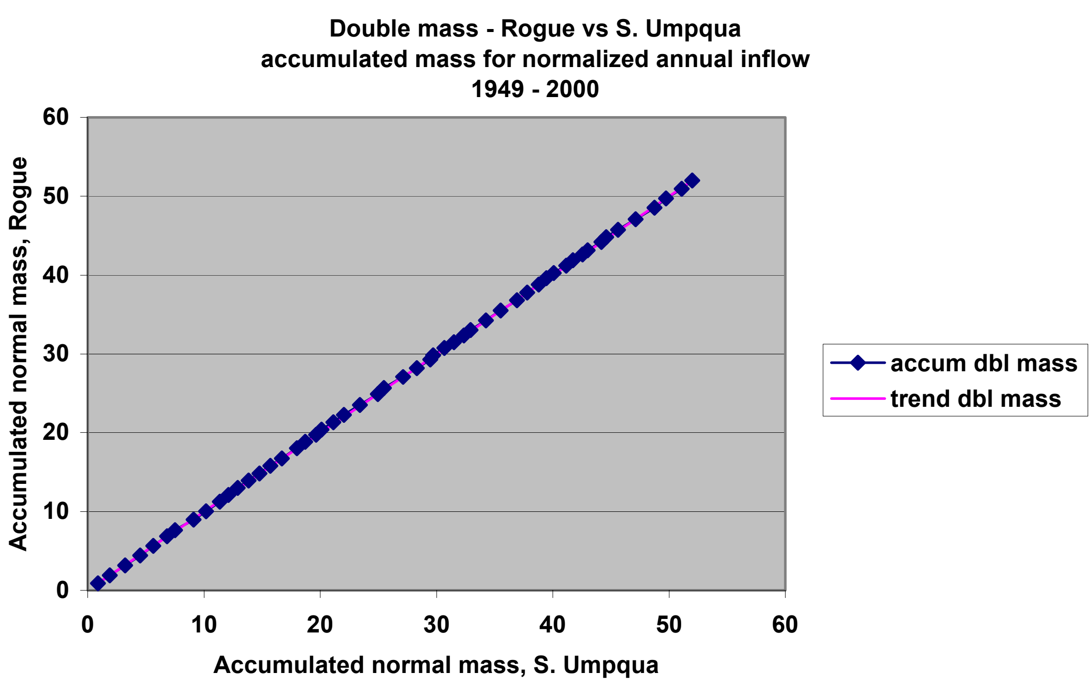




Cascades, compared to that seen on the west side of the Cascades. The double-mass curve shows the mass accumulations have no deviations, which is expected for stable records.

Trend assessments were also completed to establish the representative nature of the record for the basis station challenging the veracity of reconstructed natural flows. This station is gage 14328000, Rogue River above Prospect, which was compared against the natural flow record of gage 14308000, South Umpqua River at Tiller. This second gage is in an independent west-side watershed north of the Rogue watershed. Of note, in the assessment shown below, is the *nearly exact concordance* in trend evidenced for these two stations. The straight-line double-mass curve indicates these are stable, unaffected, natural-flow records.



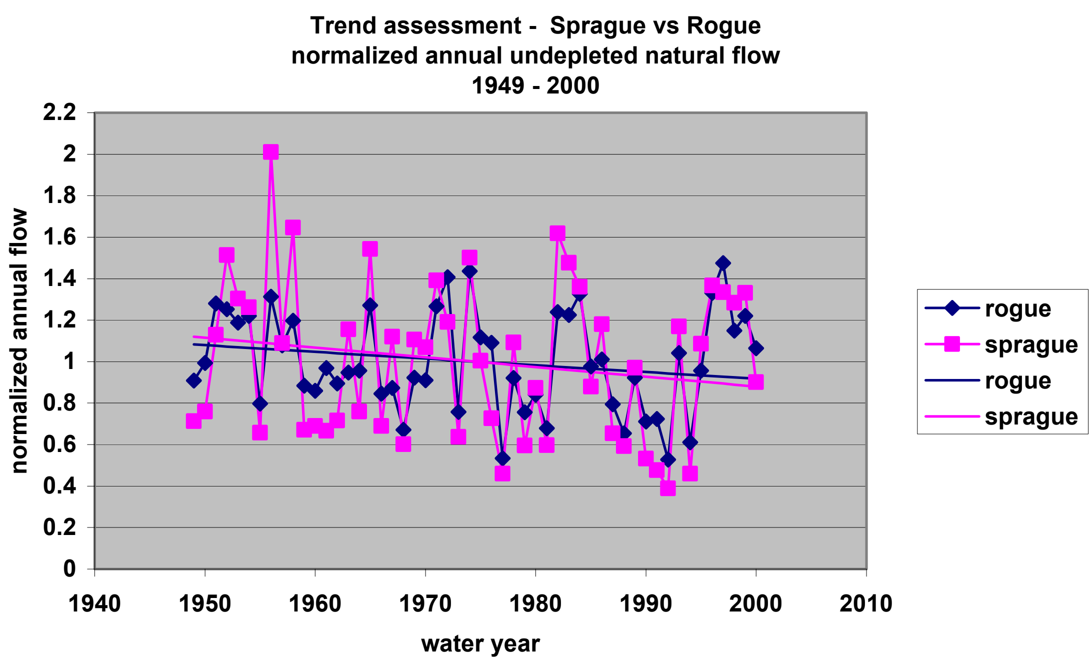


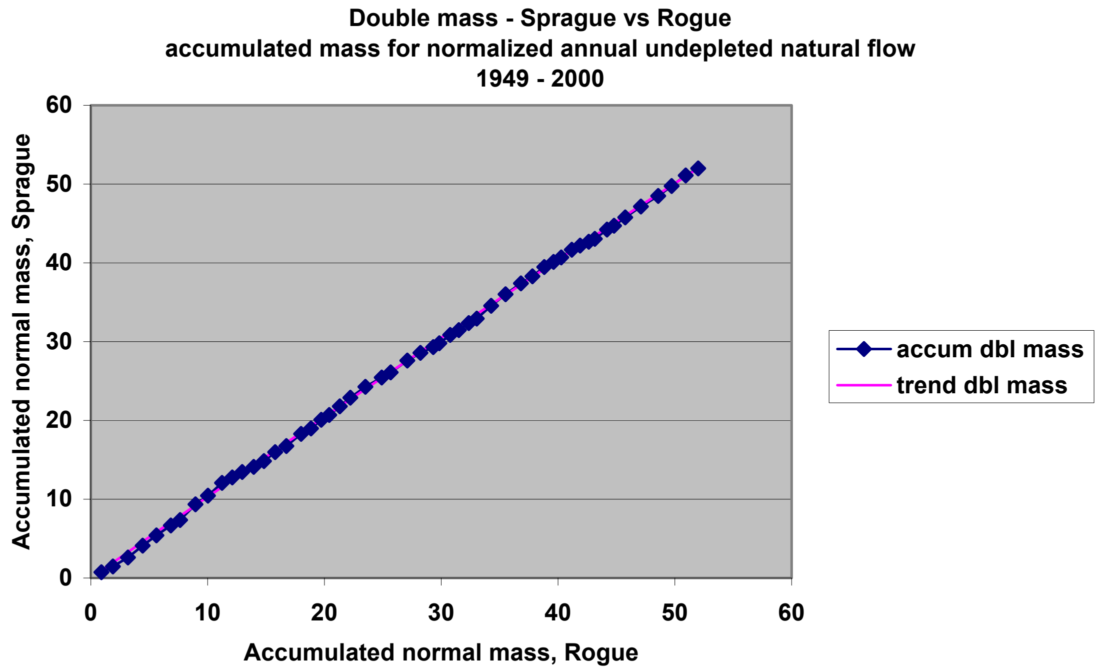
The results in comparison of the natural flow record of the Rogue with that of the South Umpqua show the gage for the Rogue provides a representative record of natural flow that may be used as a basis in challenging the veracity of other records for restored natural flow determined at regionally nearby locations. The consistency in trends noted for these records also indicates climatic dominance is consistent within the region. The independently observed consistency in trends noted for the two longer-term precipitation records that were examined, Prospect and Crater Lake, indicates a divergence in trend that, over the period of interest, has decreased over time somewhat more rapidly on the east side of the Cascades than on the west. This same indication should be evident in time-series for restored natural flow in the upper Klamath basin that are compared with the natural flow record of the Rogue.

- *The Sprague and Williamson Rivers*

The assessment of natural flow for the Sprague and Williamson was unable to account for changes in watershed condition other than an accommodation of irrigation uses and reclamation of marshlands that would affect flow of the stream. An assumption in the evaluation of these areas has been that over the period of interest, there have been no marked changes in area for either irrigation or reclaimed marshland. Although essentially false, implementation of the assumption is conservative in the adjustment of the gaged flows throughout the 52 yr period of interest, and does not, thereby, tend to underestimate natural flow of these streams. The assumption implies that irrigated areas have been stable, more or less, even though no detailed information was determined to be available regarding the locations, timing of changes, and extent of increases in these areas. Further, other modifications in watershed condition that could not be evaluated may, or may not, have affected streamflow. These modifications would include changes in the rate of clear-cutting for logging and increases in the associated areas, increased clearing of land for range and pasture, and encroachment by Juniper. Nevertheless, the resulting analysis was able to determine a representative time series for the undepleted natural flow of the Sprague and Williamson. Evidently, this may be due, in part, to the compensation caused by the addition of irrigation depletions back to gaged flow and subtraction of natural losses for reclaimed marshland.

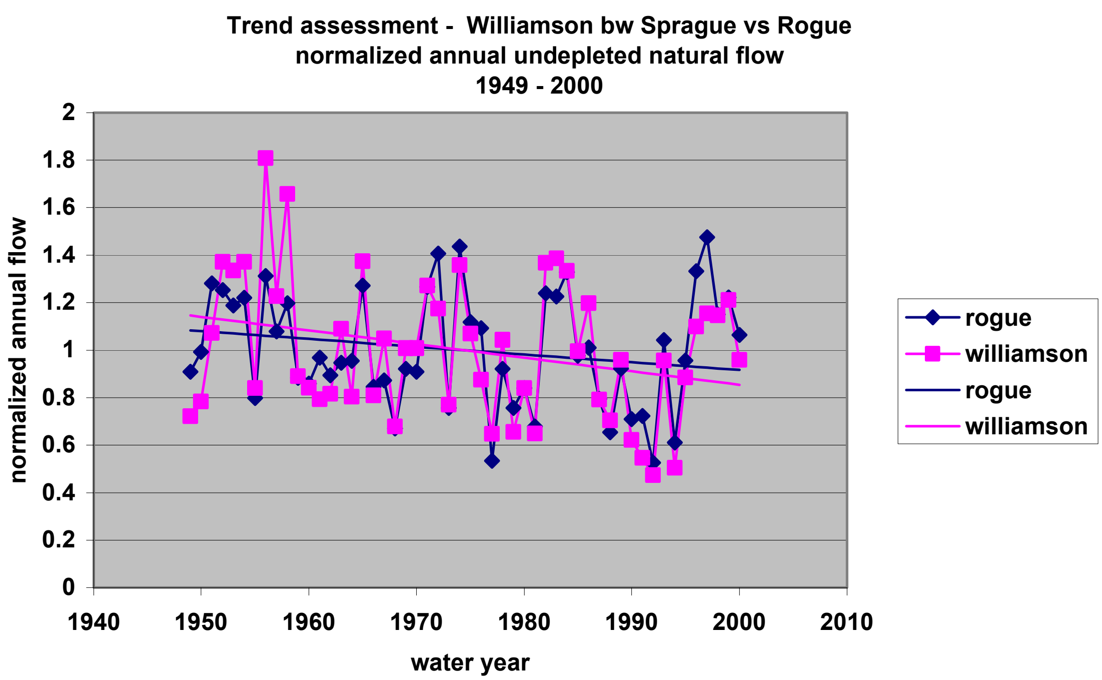
An examination of the normalized time series and double-mass curves for the Sprague, and Williamson below the Sprague, illustrate the nature of the derived results. Shown below are the results in the assessment of the Sprague. These graphs clearly show the trend for the Sprague agrees with the indication

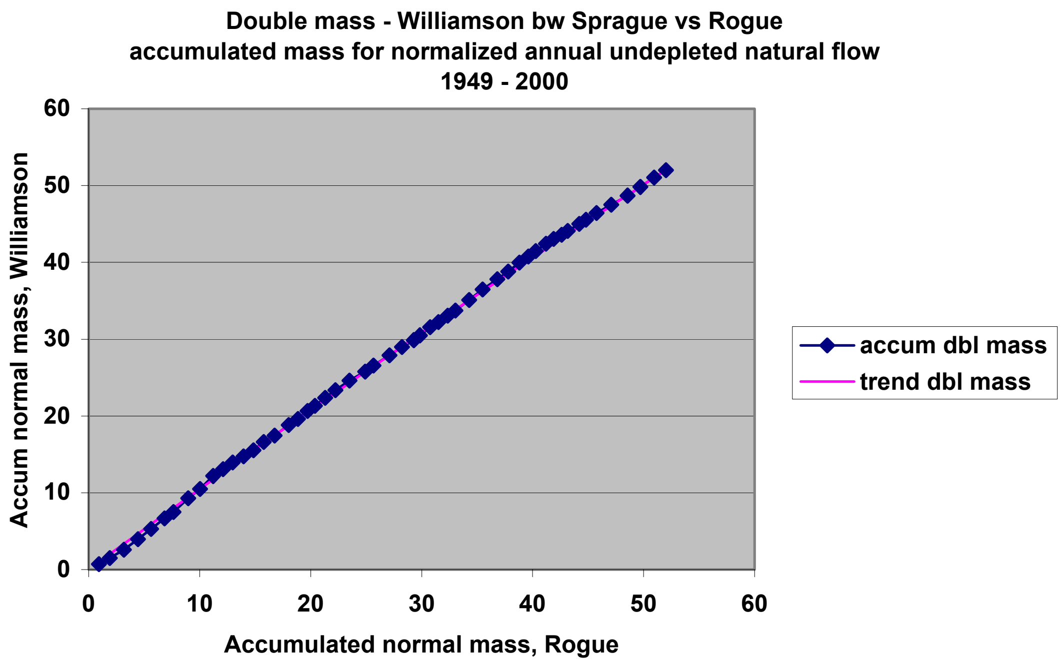




given in the precipitation analysis. The indication given by the trend for the Sprague, which is confirmed by the trend for precipitation at Crater Lake, is that streamflow, and hence precipitation, is declining at a somewhat increased rate over time on the east side of the Cascades than on the west side of the Cascades. The double-mass curve, above, indicates the reconstruction appears very good and shows no distinct deviations or abrupt changes in trend that would be characteristic of development and other changes within the watershed.

An examination of the results for natural flow of the Williamson below its confluence with the Sprague shows that with inclusion of the Williamson watershed above the Sprague, determination of natural flow for the Williamson as an inflow to Upper Klamath Lake is also representative. Trend, shown below, and



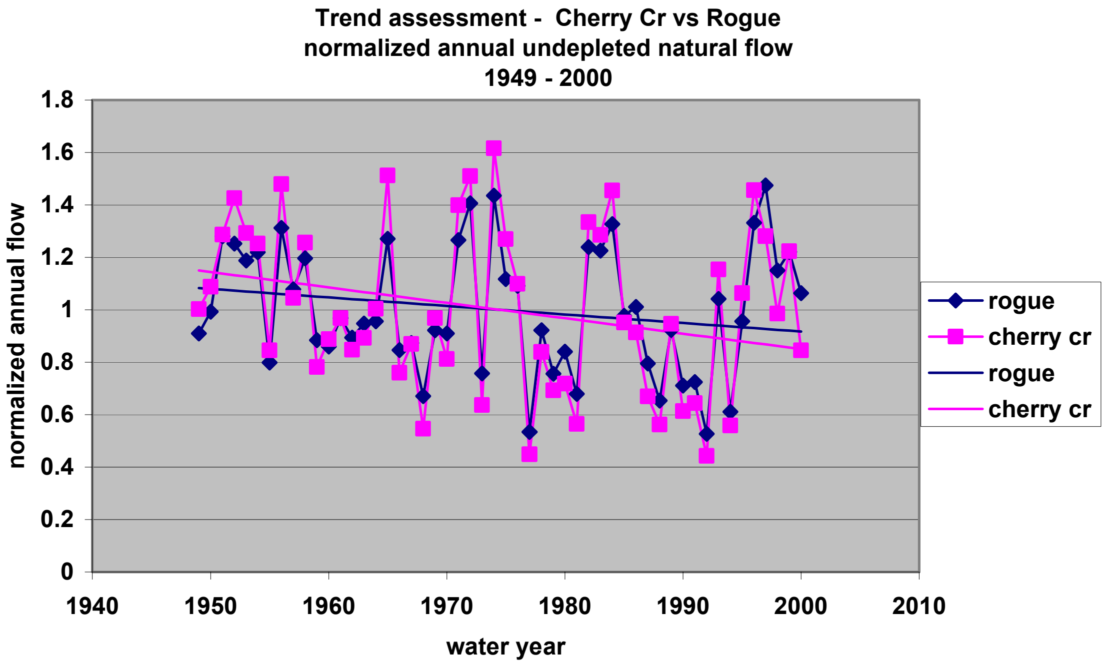


double mass, shown above, provide results that are consistent with those derived for the Sprague.

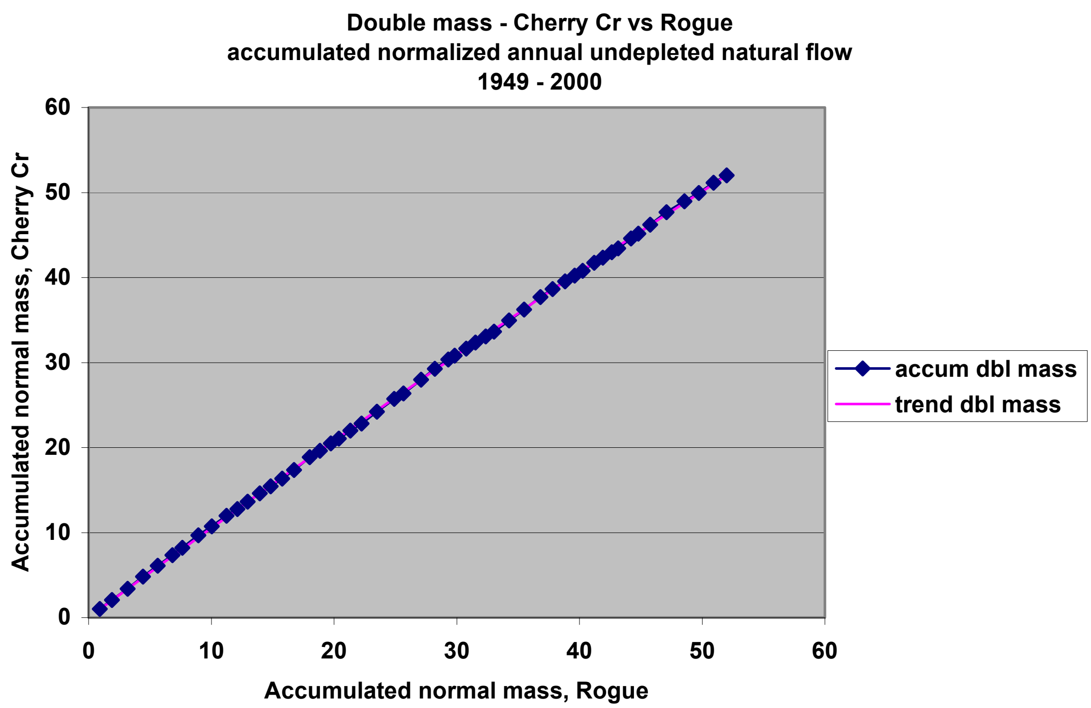
- *Cherry Creek*

Flow histories for several watersheds along the east flank of the Cascades were estimated by transference of gaged flows using the watershed characteristics method. Of special interest is the examination of statistically reconstructed flow histories forming the basis of the transference, where those flow histories did not need to be restored to natural flow. A typical type-watershed used in the transference was that of Cherry Creek. Records that are available for Cherry Creek are somewhat sparse yet sufficient for statistical reconstruction of a natural flow history covering the period of interest. Validation of the methods used, and the results obtained, was provided by the comparison of the reconstructed record with that of the Rogue. Reconstruction of the record for Cherry Creek was based on monthly flows estimated from incidental flow measurements, or on a gaged flow record for years when that record was available. The correlation analysis in the reconstruction of the full time series used a special adaptation of the procedure for fitting the line of minimum absolute deviation, where the line of correlation was curved to accommodate the base-flow deviation observed, or suspected, in the scatter plot. The gaged history for the Rogue above Prospect was the principal station used in the reconstruction. This record is also the basis station for challenging the veracity of the results.

The time series for normalized annual flow and resulting double-mass curve shows the recovery of information appears to be excellent for the reconstructed Cherry Creek time series. For the normalized annual flows, the decline in trend exhibited by the Cherry Creek annual flow time series agrees well with that for the east side of the Cascades observed in the comparison of precipitation histories for Prospect (on the west side of the Cascades) and Crater Lake. The double-mass curve shows the characteristic agreement that would be expected for comparison of two natural flow gages in essentially adjacent watersheds that are in stable natural conditions. The curve has no expressed deviations that would be indicative of changes in watershed conditions. An artifact visible in the double-mass curve is the slight curvature associated with the difference in rate of decline indicated by the trend demonstrated in the normalized annual time series. Results of these analyses are shown below.



Trend assessment - Cherry Cr vs Rogue
normalized annual undepleted natural flow
1949 - 2000
normalized annual flow
water year
rogue
cherry cr
rogue
cherry cr
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1940
1950
1960
1970
1980
1990
2000
2010



Double mass - Cherry Cr vs Rogue
accumulated normalized annual undepleted natural flow
1949 - 2000
Accumulated normal mass, Cherry Cr
Accumulated normal mass, Rogue
accum dbl mass
trend dbl mass
60
50
40
30
20
10
0
0
10
20
30
40
50
60

<u>Present-day view of the Upper Klamath Basin, and changes from predevelopment conditions</u> –

For any chosen period of record, an assessment of natural streamflow must take into account changes that have occurred in the watershed above the location at which a determination of natural streamflow is desired. All of the watershed alterations that potentially affect changes in streamflow must be surveyed, and examined. 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 representatively 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 impact except for large flows or flood events.

Wood River Valley –

Within the area of the Klamath River watershed that is tributary to Upper Klamath Lake there have been considerable changes that have altered the appearance of the landscape and changed the character of the watershed. Before development, the Wood River Valley most likely appeared as a grassland prairie with ground-water seeps and wetlands scattered along 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 marshlands probably had within them stands of Birch, Alder, Willow (*Populus* sp, *Salix* sp), Ash, Dogwood, and Elderberry, all of which are water loving trees or shrubs. Today, the Wood River Valley has been extensively reclaimed for pastureland. The riparian marshes and stands of trees are mostly gone except for those noted presently along the margin of the valley floor such as along Crooked Creek, and along Fort Creek, and in the vicinity of Wood River Springs. Streams flowing into the valley have been extensively re-channeled and diverted for flood irrigation of the pastureland. A network of drains collects end-field losses and ground water from irrigation applications and percolation losses. This drain water is successively distributed into ditches and laterals to again be used to irrigate additional pastureland. Percolation losses from flood irrigation also recharge the basin-fill ground-water reservoir of the Wood River Valley and cause increased ground-water underflow into Upper Klamath Lake. Numerous wells penetrating the basin-fill produce artesian ground water from a regional basalt aquifer that is under confined conditions. 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 ground-water discharge to Upper Klamath Lake from the regional aquifer is difficult to assess and was not determined.

Sprague and Williamson Rivers –

Similar changes may be noted along the streamcourse of the Sprague River. Much of the marshland and valley-bottom wetland in the upper Sprague, in the vicinity of the towns of Beatty and Sprague River, has been reclaimed and is irrigated. The primary crops include alfalfa and hay grass. Water is diverted from the Sprague just above its confluence with the Williamson River for irrigation of land on the Williamson delta adjacent to Upper Klamath Lake. However, along the streamcourse of the Williamson River, to which the Sprague is a tributary, there are few changes 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 takes place above Klamath Marsh. Alfalfa and hay grass are the primary crops.

Within the Sprague and Williamson watersheds, and especially that of the Sprague, 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.

Other changes in the Upper Klamath watershed -

Other changes in the watershed include clear-cutting for timber harvest, land clearing for pasture and ranching, suppression of fire in forested areas, and the consequent invasion of juniper which forms stands in clearings and in areas adjacent to forest land that were not previously known to have juniper. Extirpation of beaver, channelization and diking of 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. These aspects are very difficult to assess on a month-to-month basis. Well managed forest clear-cutting may have little overall hydrologic impact. Invasion of juniper may offset increased runoff from agricultural clearings. The hydrologic consequences from changes such as clear-cutting, land clearing, and juniper encroachment, may offset one another to produce little end result or noticeable effect. The changes from extirpation of beaver are readily seen in channel entrenchment and the loss of woody debris within or adjacent to stream channels, loss of extended stream baseflow, loss of flow detention in higher flow events, and the elimination of detention losses to evaporation, bank storage, and to attendant marshes that were caused by beaver ponds.

A general conceptual view of the Upper Klamath watershed is given in Figure A. The description given with the figure caption explains the conceptual process required to estimate pre-development natural flow.

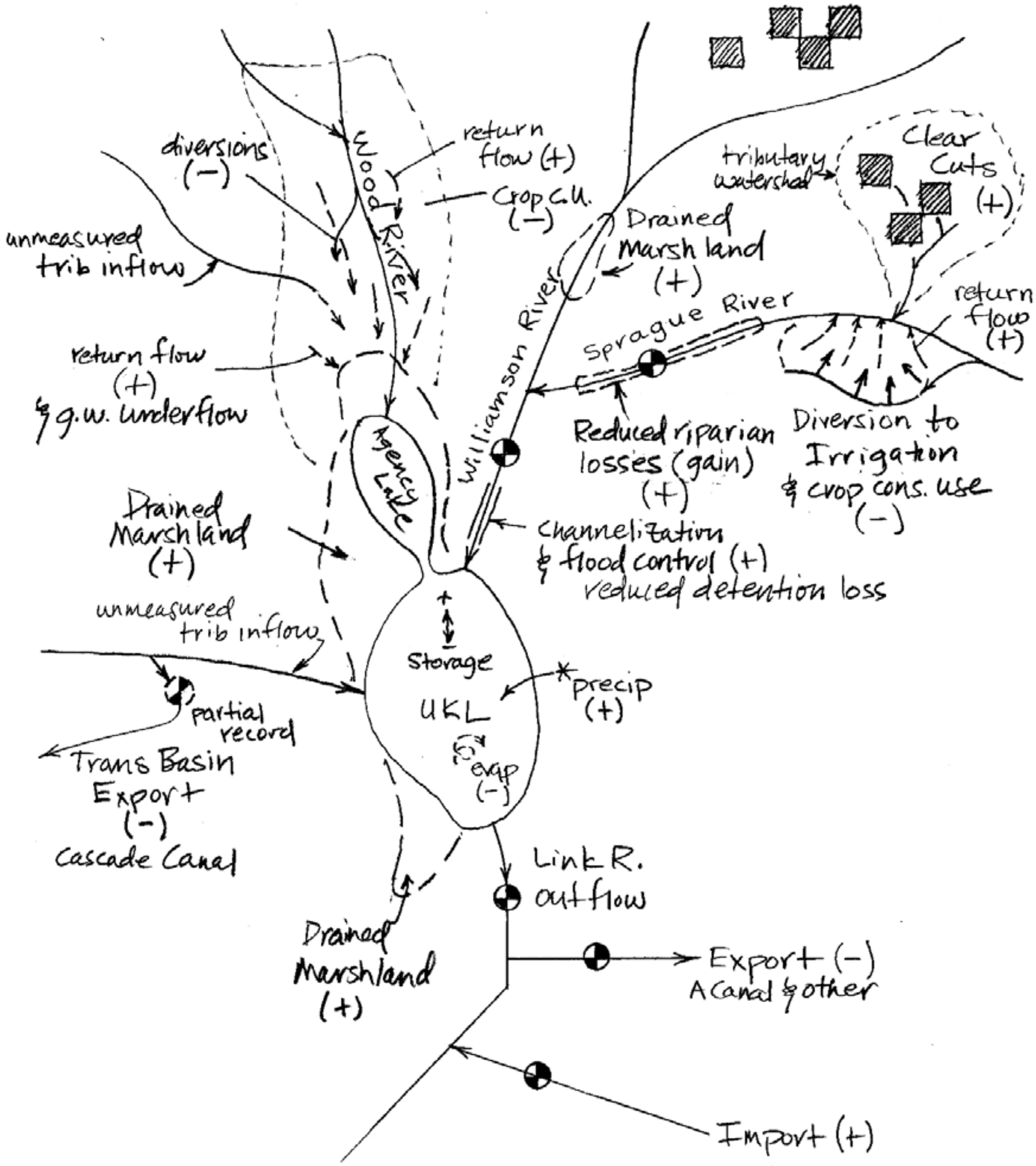


Figure A. Cartoon of present-day watershed of Upper Klamath Lake. For a generalized view of the water budget shown in this conceptual view, changes in streamflow due to current conditions are indicated by (+) for gains in flow or (-) for losses in flow. As a general rule for the water budget, + and – factors in the watershed above the lake must be reversed to determine undepleted natural inflow to the lake, and must consider unaccounted natural losses that were reclaimed by development. Assessment of Upper Klamath Lake as a natural water body and determination of undepleted 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, lake wetland marsh evapotranspiration, and water surface evaporation that would have occurred under natural, pre-development conditions.

<u>General methodology for determining the natural inflow to Upper Klamath Lake</u> –

The general method used in the reconstruction of natural flow for the Sprague and Williamson Rivers is similar to that used by the Engineering Advisory Committee to the Upper Colorado River Commission in the reconstruction of the undepleted natural flow of the Colorado River. The procedure for reconstruction of the undepleted natural flow is to add depletions due to irrigation and other uses to the gaged flow, subtract from the gaged flow the return flows caused by those uses, and subtract from the gaged flow the use that would have been incurred by natural marshland that has been reclaimed for irrigation uses. In addition, the change in evaporation (a loss or gain to flow) caused by the estimated change in open water surface of the stream now having undepleted flow is algebraically added to the estimated undepleted flow. Because this adjustment for evaporation was seen to be much less than 0.1 percent of the final determination for the undepleted natural flow reconstructed for the various segments of the Colorado River, and its tributaries, the adjustment for evaporation changes in open water surface area for the Sprague and Williamson was not assessed. However, an extensive evaluation was completed regarding irrigated areas and attendant consumptive uses within the Sprague and Williamson watersheds. Reclaimed natural marshland areas were also assessed and the restored natural flow for each of these streams accounts for these changes.

The natural inflow from the Wood River Valley to Upper Klamath Lake was determined, in part, by transference of watershed characteristics and rescaling of gaged flows from nearby watersheds to ungaged watersheds along the east flank of the Cascades that produce inflow to Upper Klamath Lake. Correlation analysis was used to determine the longer-term flow history of streams within the Wood River Valley that already had natural flow gaging records of sufficient length. For spring-fed streams such as those on the east side of the Wood River Valley, estimated natural flows were reconstructed from either incidental and miscellaneous flow measurements made by the USGS, and others, or estimated in part from gaging station records and measured flows existing at inflow nodes to the Wood River Valley. Because the developed records for these determined flows are already naturalized and for nodes at the outer edge of the valley floor, losses incurred by inferred natural riparian areas along streamcourses traversing the valley floor were subtracted from those respective flows to determine the natural inflow from each stream, or group of streams, to Upper Klamath Lake. Use of these methods obviated the need for adjustments to streamflow to account for irrigation practices, and thereby reverse the affects of irrigation diversions, application of irrigation water, incurred crop consumptive uses, incurred percolation losses to the ground-water reservoir, and evaluation of return flows that would have been necessary to account for present development conditions and restore these flows to undepleted natural flow.

<u>Northern and western Wood River Valley natural streamflow determination</u> –

Introduction

Inflow to Upper Klamath Lake was quantified by developing synthetic natural time series for all contributing areas in the valley. Specifically, the northern and western tributary streams are discussed herein. A standard methodology was developed and followed to quantify each tributary's inflow between October 1947 and September 2001. The process used is described below and the application to each specific watershed is outlined in detail.

Not all watersheds in the Klamath and Rogue River basin have the same basin characteristics. Varying geology and dominant flow regimes warranted the necessity of several basin specific approaches. Drainages like Fourmile Creek, Annie Creek, and Sun Creek were not generated using the standard process that was otherwise followed. How the synthetic time series for these basins were developed is also described in detail.

Standard Streamflow Quantification Methodology

Even though the floor of the Wood River valley has been altered significantly within the last 100 years, most of the contributing headwaters remain in a relatively natural condition. The first two logical steps for quantifying streamflow in relatively ungaged rivers are:

1. Obtain all available gaged data, including any miscellaneous, instantaneous streamflow measurements, and
2. Determine how natural these data are.

Several years of gaged streamflow information is available for Upper Klamath Lake and Wood River tributaries, and the majority of that data can be considered natural or "unregulated." In order to determine how natural the available data are, the presence of any upstream diversions into or out of the stream should be determined and quantified, as well effects of any major land characteristic changes such as those resulting from timber harvesting. The measurement or gage location should be investigated to ensure the majority of water captured or produced by the watershed is measurable at the surface. Several tributary gages were located on alluvial fans or on an alluvial valley bottom where a significant amount of water that is produced by the watershed and contributes as inflow into Upper Klamath Lake may be in the subsurface at that particular location. Where deviations from the desired natural condition were evident, adaptations to this process were made to naturalize the gaged streamflow data based on site specific needs before continuing with the standard process.

Streamflow measurements used in this investigation are available from the United States Geological Survey (USGS), the United States Department of Agriculture - Forest Service (USFS), and Oregon Water Resources Department (OWRD). Most USGS data are readily available in CD-form from Hydrosphere, but miscellaneous and peak streamflow measurements are mainly found in the Water Resources Data Publications for Oregon, including summary and individual water year volumes. The USFS 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, OR. Miscellaneous streamflow measurements collected by OWRD can be downloaded from their website, but some issues were evident when trying to use these data.

Temperature and precipitation data were not used in the standard process, however these data were integral in estimation techniques employed for unique watersheds, such as Annie Creek and Denny Creek. Such data are available from the Oregon Climate Service or the National Oceanic and Atmospheric Administration. Incomplete data records were extended using the same techniques employed for streamflow record extension, as described by Reid, Carroon, and Pyper (1968) for the state of Utah. Watersheds were delineated using a Geographic Information System (GIS) and electronic topographic maps (Digital Raster Graphics) available on the USGS EarthExplorer website. Other GIS information was collected from the USFS and the state of Oregon, which provided several basic GIS information layers.

As stated before, the process to determine a synthetic time series for most tributaries was generally identical. The subsequent steps in the standard process are:

3. Determine similarities between 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 2 other concurrent daily gaged records.
5. Related monthly total discharges to those from nearby, similar gage with large period of record.
6. Create a synthetic natural time series based on monthly total flow correlation equations.

In determining the similarity to other watersheds, several basin characteristics were compared. The geology, variation in areal precipitation, climate, aspect, and dominant flow factors of each basin were characterized to find similar gaged and ungaged watersheds. The separation between watersheds also determines the transferability between similar watersheds.

To determine the best gage transference methodology and equation, gaged streamflow information was initially transferred between all adjacent gaged watersheds using basin characteristics. Such characteristics as watershed area, weighted-average annual precipitation from 1961-1990, and effective precipitation (average annual precipitation / drainage area) were used to rescale the time series from a known gage to represent another (gaged) watershed. In all transference cases, the resultant synthetic time series could not recreate the variability exhibited by the other known gage, except in one case. The only transference that generated adequate variability used a gage in a non-adjacent watershed, from over 36 miles to the northeast. Despite being able to recreate adequate variability between gaged watersheds, an equation to accurately transfer this gage to ungaged watersheds could not be developed due to the inability to produce a sufficient least-squares best-fit line. Climatic variation evident across the distance between this gage and the Wood River Valley did not support confidence in using this equation as the synthetic time series, since derived results would not have been representative or accurate.

Most Klamath Lake basin watersheds had several years of daily gaged data, but the data available was still minimal. In order to build a larger data set, monthly total flow estimates were made using concurrent instantaneous streamflow measurements. When sufficient concurrent measurements were available between a nearby, daily record and the desired watershed, at least one measurement per month for several months, monthly total flows for the otherwise ungaged watershed was estimated by rescaling the somewhat extensive daily gaged records from nearby watersheds. This rescaling is sometimes termed hydrograph-matching and was typically done with at least 2 nearby gages, which generally produced very similar results. After creating an estimated daily gage record for the desired watershed, daily values were summed by month to create total monthly discharge estimates. Only estimates that were generated from concurrent instantaneous flow measurements observed before, during, and after that month were considered to be accurate and were used in further correlation analyses.

Since an accurate basin-characteristics-based equation could not be determined, a variety of linear and curvilinear correlations were used to develop each synthetic time series. Numerical correlation methods are considered to provide more accurate baseflow characteristics and streamflow variability for the Wood River Valley than any of the watershed characteristics techniques considered. For most watersheds in the valley, the several years of gaged information represents natural conditions, since land management activities have not affected the streamflow hydrograph (USDA, 1994; USDA, 1995; USDA 1996). A correlation between these data and another gage with a more extensive period of record was the common procedure used. Monthly total discharge values from a nearby, similar gage record were correlated to those from each desired watershed. 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. The least-squares method defined by Pollard (1977) was used to determine the accepted best-fit line. However, the least-squares line does not always capture sufficient variability and capturing sufficient variability is imperative. The amount of explained variability captured by a line is determined by calculating r^2 (Lapin, 1983) as modified for the line of minimum absolute deviation (MAD) or a generally similar fitted line (Zebrowski, 1979; Troutman and Williams, 1987; Williams 1983). The use of these modified lines ensured sufficient variability was recovered. Actual gaged monthly total flows were considered more accurate and depended on more heavily than monthly estimates. Correlation equations were used to develop synthetic time series from October 1947 to September 2001.

The following Wood River tributaries were quantified using the standard process described above:

Stream Name:	Natural Tributary to:
Sevenmile Creek	Upper Klamath Lake
Threemile Creek	Crane Creek
Nannie Creek	Cherry Creek
Cherry Creek	Fourmile Creek
Rock Creek	Crystal Creek
Moss Creek	Upper Klamath Lake

The time series for each watershed was developed uniquely and is explained in more detail below. Any deviations from the standard process are described, along with a qualitative discussion of each synthetic time series.

<u>Sevenmile Creek</u> – below Short Creek and above Mares Egg Spring

Sevenmile Creek begins in the east Cascades south of Crater Lake, in the northwestern area of the Wood River Valley. The entire drainage area including Short Creek is approximately 50 mi^2. The two major sub-watersheds are Dry Creek, which is 13.3 mi^2 in area and is located on the north side, and Sevenmile Creek, which is 12.1 mi^2 in area and lies immediately to the south. About 58% of the Sevenmile Creek sub-basin is protected by the Sky Lake Wilderness areas, and 62% of the Dry Creek sub-basin is also wilderness. Only about 5% of entire drainage area is private land. Despite timber harvesting and road construction activities on USFS land, the magnitudes and peaking of streamflow in Sevenmile Creek above irrigation diversions area likely to not have been significantly affected from natural conditions (USDA, 1995). Therefore, gaged streamflow measurements taken above irrigation diversions are considered natural.

The headwater area of Sevenmile Creek begins along the east side of Cascade Ridge where an abundance of glacial till and loose unconsolidated volcanic material is located. The watershed is dominated by pumice soils, especially in the Dry Creek drainage, which has a high infiltration rate. Therefore, the fact that Sevenmile Creek has lower peak flows per drainage area than other western Wood River Valley stream is not surprising.

The high elevation peaks of Sevenmile Creek, particularly Klamath Point and Pelican Butte, are composite volcanoes composed of ashes and blocky basalt flows. These areas have very little drainage network, which implies groundwater recharge occurs here. Springs can be found at the valley bottom along the edge of wetlands, which are most likely fed by ground water recharge occurring in the Sevenmile drainage (USDA, 1995). The natural, synthetic time series developed for Sevenmile Creek attempts to account for surficial streamflow and water released by these springs at the bridge below Short Creek.

The USFS has maintained a daily recording streamflow gage on Sevenmile Creek below Dry Creek since October 1992. These values were measured above irrigation diversions, but these data are likely lower than the actual amount of water produced by the Sevenmile/Dry Creek watersheds, since the observation site is located on an alluvial fan. Consequently, a portion of flow has probably gone subsurface upstream at the top of the alluvial fan.

Several miscellaneous flow measurements were collected by the USGS in 1992-1993. Measurements were taken above Dry Creek, as well as downstream below Short Creek and several unnamed springs. These measurements are concurrent with the USFS record, so relationships were developed between the USFS gage and measurements taken below Short Creek in order to develop monthly total streamflow estimates for Sevenmile Creek below Short Creek from October 1992 to September 2001. February of 1999 was not estimated since the USFS gage was not continuous during this time period.

In general, Short Creek and the unnamed springs provided at least an additional 30 cfs to Sevenmile Creek. Only 2 streamflow measurements were collected when upstream diversions were not in use and were concurrent with the period of record of the USFS gage. These measurements taken in autumn and were used to estimate baseflow contributions from the unnamed springs and Short Creek. Larger increases between the two gage sites were seen during spring runoff, which varied by at least 81 cfs, but unmeasured diversions between the two locations make it impossible to back-calculate the natural amount of water available with sufficient confidence. Part of the flow measured below Short Creek may also be accounting for water from the Sevenmile and Dry Creek watersheds that went subsurface and is not accounted at the USFS gage. The synthetic time series developed for Sevenmile Creek below Short Creek therefore accounts for the water produced by the unnamed springs, all the water observed in the USFS gage below Dry Creek, some of the water that went subsurface upstream of the USFS gage, and some water related to spring runoff in the intermediate area below the USFS gage.

The monthly total flow estimates below Short Creek were used to create a complete synthetic time series for Sevenmile Creek between October 1947 and September 2001. This correlation analysis was completed against the Rogue River above Prospect gage on a month-by-month basis. Good correlations were found between the Sevenmile estimates and the Rogue River above Prospect gage, and sufficient variability was apparent in each month. The combination of the original monthly total streamflow estimates and those derived from the line of minimum absolute deviation for each month composes the synthetic time series for Sevenmile Creek below Short Creek, with one exception.

Several instantaneous streamflow measurements were collected below Short Creek by the USGS between August 1949 and October 1962. Of these values, most can be considered natural, because the upstream irrigation canal was noted as being "dry." For the other measurements where the diversion canal was not dry, a flow measurement was collected for the diversion canal. By adding together these streamflow and diversion flow measurements, these streamflow measurements were naturalized. All of these natural values were used to rescale the Rogue River above Prospect and Red Blanket Creek daily gage records to estimate monthly total flows for several autumn months between 1950 and 1962. The monthly totals found by rescaling the two gaged records yielded very similar results, generally within 10% of each other. Even though only 2 of these measurements were noted as "baseflow" by the USGS, these estimates will be referenced to as baseflow estimates since they were only for early autumn months.

These baseflow month estimates were considered accurate for natural flow in Sevenmile Creek below Short Creek. The month-by-month least-squares procedure was attempted using these estimates, along with the estimates generated between 1992 and 2001. The September and October coefficient of variation, or r^2 values, reduced significantly upon their inclusion from those found when using only the 1992-2001 estimates. The reason for this reduced variability was that baseflow measurements below Short Creek may be quite stable due to the influx of spring flow. The baseflow estimates generated between 1992 and 2001 are more dependent on the baseflow recession rate at the USFS gage. The baseflow recession rate at the USFS gage most likely has more variability than the baseflow rate below Short Creek. The gage below Short Creek is more dependent on spring-fed flows than the USFS gage, and the USFS gage may be underestimating baseflow due to the alluvial fan location. Since greater variability is considered to more accurately represent natural streamflows, these less variable monthly total flow estimates were omitted in the least-squares line development. These values were considered accurate, though, as they directly resulted from gaged information. Therefore, they were used in the final synthetic time series in place of values derived using the MAD line to provide additional calibration to the Sevenmile Creek synthetic time series.

Threemile Creek – at outlet

The Threemile watershed lies just south of the Sevenmile drainage and totals 9.7 mi^2 in area. Threemile Creek flows perennially into Crane Creek on the valley floor, and streamflow is dominated by spring snowmelt runoff. The geology of the watershed is similar to Sevenmile, with cinder cones defining the northern and southern ridge tops and abundant loose unconsolidated volcanics. High infiltration rates in these soils limit streamflow yield. The southern ridge tops probably provide ground water recharge for springs on the valley bottom, such as Mares Egg Spring.

The Threemile Creek watershed is partially protected by the Sky Lake wilderness of the Winema National Forest. About 50% of the Threemile watershed lies within the wilderness area, while the remaining portion is non-wilderness. Despite some timber harvest and road construction in the watershed, there appears to be no effect from these activities on timing of peak flows. Although Threemile Creek was only intermittent previously, due to water going subsurface into the alluvial fan upstream of the confluence with Crane Creek, the current perennial flow has been attributed to natural channel downgrading that occurred during the 1964 flood. During this storm, the channel bottom was lowered by about 10 ft, thereby bringing the stream closer to the water table (USDA, 1995). Therefore, the magnitude and timing of flows observed by gaged streamflow measurements are considered to be natural.

The USGS collected instantaneous and streamflow measurements about once a month between September 1964 and October 1967 at an appropriate upstream location that is not on an alluvial fan. The USGS created monthly total flow estimates from these numbers (Hubbard, 1970). The USGS also collected annual peak flow measurements mainly between water years 1965 and 1974, so the peak flow measurements allowed for precise reconstruction of monthly totals between 1964 and 1967. Reconstruction of monthly total flow was completed by rescaling the Varney Creek and South Fork Rogue River (S.F. Rogue + S.F. Power Canal near Prospect) gages. The estimates generated from each gage varied slightly, particularly in the late summer and early autumn, mainly because Varney Creek exhibited a lack of surficial baseflow, unlike Threemile Creek and South Fork Rogue River. Otherwise, the reconstructed values were similar to those developed previously.

The USFS also collected miscellaneous flow measurements between December 1991 and May 1997. Monthly total estimates were generated for several months from the Rogue River above Prospect and Cherry Creek gages. All estimates were used to develop correlations between the extended synthetic time series for Cherry Creek (see Cherry Creek). Specific month correlation equations provided additional calibration for March through July, while a generic equation encompassing all estimates was applied to the other months. The final synthetic time series yielded very similar results to expected values.

On July 29, 1992, the USGS collected instantaneous streamflow measurements at 2 different locations. One measurement was taken at the old-USGS gage location, where all other USFS miscellaneous flow measurements were taken, while the other measurement was taken upstream. The downstream gage location is unfortunately located on an alluvial fan, whereas the upstream location is in a V-notch valley. As is expected, the upstream value of 0.83 cfs is almost 4 times higher than the 0.21 cfs measured on the alluvial fan. Apparently a significant amount of water goes subsurface from Threemile Creek due the alluvial fan. The majority of available streamflow measurements were taken on the alluvial fan, and since there is only one day that concurrent measurements were taken at the 2 locations, estimating the lost water for inclusion in the Threemile synthetic time series is not possible with any accuracy. Therefore, not all water produced by the Threemile Creek watershed could be accounted without further field work, but the synthetic time series developed is representative of flow available on the surface. The water that became subsurface at the alluvial fan is most likely captured and released through evapotranspiration by the wetlands 2/3 mile downstream.

Nannie Creek – at outlet

Nannie Creek is only 3.5 mi^2 in area and lies on the west side of the Wood River Valley, just south of Threemile Creek. While only 9% of the drainage has equivalent clearcut acres, caused by harvesting over the past 25 years, the most significant change to hydrologic processes in the watershed has resulted from alteration of the fire regime. Fire suppression in the Nannie Creek drainage has increased the amount of area with 70-100% canopy closure from 2 to 27% since 1940. This increase in canopy cover may be altering the peaking of snowmelt runoff, since less sunlight reaches the snow pack, but these effects have yet to be quantified (USDA, 1994).

Since only limited information was available regarding effects to streamflow, a synthetic natural time series was made assuming USGS gaged streamflow measurements were not significantly altered from natural conditions. Instantaneous streamflow measurements were collected by the USGS between August 1964 and October 1967. Monthly total flow estimates were generated by rescaling daily gaged records from Varney Creek, which had similar peaks and baseflow regime as Nannie Creek, and South Fork Rogue River (S.F. Rogue + S.F. Power Canal near Prospect). The USFS also estimated baseflow and peak measurements in 1993 (USDA, 1994), but the monthly total estimates developed from these data were not considered accurate enough for use in correlation equation development. These estimates were only used to verify calculated values.

Very few monthly total streamflow estimates could be generated. The monthly flow estimates usable in completing a correlation analysis were restricted to values above zero, since several months had no flow, so only 10 data points (monthly totals) were available for the analyses. Only one general equation was developed to make synthetic time series for Nannie Creek. This equation relates concurrent monthly totals against Cherry Creek data to create a synthetic time series from October 1947 to September 2001.

The quality of the Nannie Creek synthetic time series is obviously lower than other Klamath Lake basin watersheds. The reasons for a lower quality record are:

1. A continuous daily gage record was not available.
2. Very few monthly total flows could be estimated.
3. The estimates made were only for 1964-1967, rather than more than one time period.
4. Month-specific equations could not be determined due to lack of data.

Despite the inability to calibrate these numbers with more accuracy, the monthly total estimates used in correlation exhibit sufficient variability to represent the natural streamflow of Nannie Creek. During the period of record of gaged data, between 1964 and 1967, a complete range of streamflow measurements were observed in Nannie Creek. In December and January 1964, a significant flood event occurred across the far western states, which is apparent in the December 1964 Nannie Creek streamflow measurements. For low flows, Nannie Creek was observed to be dry in September of 1966 and 1967. Intermediately, 8 other monthly flow estimates defined the typical flow regime of Nannie Creek. Though the synthetic time series for Nannie Creek is not based on numerous data points, a representative time series was generated by capturing sufficient variability.

<u>Cherry Creek</u> – at outlet

The Cherry Creek drainage is 16 mi^2 in area and lies on the west side of the Wood River Valley, just south of Nannie Creek. The watershed aspect is east-west, and the flow direction is to the west. The original stream split into three main channels atop an alluvial fan below the watershed outlet, which either flowed into Fourmile Creek or directly into downstream wetland areas. Flow is now diverted for irrigation purposes near the watershed outlet or is channelized into Fourmile Canal. More than half of the watershed is protected by the Sky Lakes Wilderness and has been relatively unaltered by land management activities. The remaining area has experienced minimal harvest activity during the last 25 years, and only 1% of the entire watershed has been affected by clearcuts (USDA, 1994).

The USFS has maintained a daily recording gage on Cherry Creek since October 1992. Unlike other Wood River Valley tributaries, the available gaged data for Cherry Creek were taken in an excellent location, within a constricted valley above the watershed outlet. These data are considered to be highly reliable natural streamflow measurements due to their prime measurement location and the consideration that flows at this location have not been significantly altered due to land management activities (USDA, 1994).

Instantaneous streamflow measurements were made by the USGS between 1964 and October 1967. Monthly total estimates were generated from these data by rescaling the Varney Creek and South Fork Rogue River (S.F. Rogue + S.F. Power Canal near Prospect) gaged records. The estimates generated from each gage varied slightly, particularly in the late summer and early autumn, mainly because Varney Creek exhibited a lack of surficial baseflow, unlike Cherry Creek and South Fork Rogue River.

The USFS also collected streamflow measurements between December 1991 and July 1992. Total monthly flow estimates were made by rescaling the Rogue River above Prospect daily gaged record. This was the only record rescaled because it was the only natural daily flow recorded during that time period near the Wood River Valley. These monthly total flow estimates were combined with the 1960s estimates and gaged records to develop the synthetic time series.

Gaged and estimated monthly totals were used to create a complete synthetic time series for Cherry Creek between October 1947 and September 2001. The derivation procedure used the same generalized correlation procedure modified for the line of minimum absolute deviation to estimate values between October 1947 and September 1992. This correlation analysis was completed against the Rogue River above Prospect gage on a month-by-month basis. Relatively good correlations were found between the Cherry Creek estimates and the Rogue River above Prospect gage. Despite having several low r^2 values in the summer months of July and August, trends exhibited in the gaged data are quite prevalent and are reproduced in the synthetic data.

Cherry Creek has geologic features typical of the eastern slopes of the Cascades. The headwaters begin with steep rock escarpments and talus slopes that drain into the Cascade summit, characterized by broad, flat plateaus with abundant kettle lakes and wet meadows. Steep, heavily forested slopes of the lower watershed descend to the lacustrine environment of the Upper Klamath Lake Basin (USDA, 1994). The same land-forming processes occurred all along the east side of the Cascade Range; therefore all western Wood River Valley streams are characterized by basaltic lava material overlain by pumice ash deposits. As a result, the complete synthetic time series for Cherry Creek was used to generate synthetic time series for these other watersheds under the following premises:

1. Similar geology and sedimentation leads to similar permeability and water-bearing capacity.
2. Streams on the east side receive less rainfall than the watersheds to the west, where the majority of gaged streamflow data are available, so deriving a quality synthetic record from Cherry Creek is more accurately relatable to other Wood River Valley tributaries than using data from over the ridge.
3. The gaged data available for Cherry Creek are considered highly representative of all the water produced by the Cherry Creek drainage, since the gage location was placed in a constricted, V-notch valley.
4. The synthetic time series for Cherry Creek was used in generating time series for Threemile Creek, Nannie Creek, Rock Creek, and Moss Creek.

Instantaneous streamflow measurements were made by the USGS between 1964 and October 1967. These data are available from the OWRD website, but cross-checking with the original data published by the USGS revealed several errors in the OWRD data. These errors were corrected, and updates related to the other watersheds were made based on the corrected Cherry Creek data.

<u>Rock Creek</u> – at Upper Klamath Lake

The Rock Creek drainage is 16.5 mi^2 in area and lies on the west side of the Wood River Valley, just south of Cherry Creek. About 33% of the watershed is within the Sky Lakes Wilderness, and only 3.6% of the watershed has equivalent clearcut acres. There are no diversions into or out of Rock Creek. The streamflow measured at the outlet is therefore considered relatively unaffected by land management practices or diversions (USDA, 1994).

The USGS, USFS, and OWRD have collected numerous miscellaneous flow measurements on Rock Creek. Similar to other watersheds, the USGS collected instantaneous streamflow measurements between

December 1964 and October 1967. These data were previously used to develop monthly total estimates (Hubbard, 1970), but several months were redeveloped by rescaling Varney Creek and South Fork Rogue River daily gages. In the 1990s, OWRD measured streamflow between December 1991 and May 1993, and the USFS measured streamflow between December 1991 and May 1997. These measurements were combined in order to make monthly total streamflow estimates for several months between 1992 and 1997.

The measurement location of the USFS (1990s) data is upstream from the USGS (1960s) site. This downstream site is located on an alluvial fan where Rock creek meets the Klamath Lake basin. The USGS measurements are most likely to underestimate the full amount of water being released from the Rock Creek drainage due to the location of the gage measurements and the likelihood some water had gone subsurface at the top of the alluvial fan. Unfortunately, there are no concurrent measurements between these two sites, so further field work would be necessary to adjust the 1960s data to a more natural condition. Consequently, the 1990s estimates were relied on more heavily in the development of natural streamflow correlation equations.

Correlation equations were developed to create a Rock Creek synthetic time series from October 1947 to September 2001. A general correlation based upon the synthetic natural time series for Cherry Creek was used for most months, but month-specific equations were developed for May through September. Despite being similar to Cherry Creek in size and average precipitation, the Rock Creek drainage produces far less streamflow. The reason for the lower flow levels may be based on slightly different geology and water retention capabilities of the watershed (USDA, 1994). The Rock Creek synthetic time series is considered to be natural and representative of water that would be released to Upper Klamath Lake by the Rock Creek drainage.

<u>Moss Creek</u> – at Upper Klamath Lake

The Moss Creek watershed is 8.3 mi^2 in area and drains into Ball Bay of Upper Klamath Lake. About 77% of this watershed area is protected by the Mountain Lake Wilderness area of the Winema National Forest, and an additional 12% is within National Forest Boundaries. The remaining 11% is most likely privately owned. In comparison to other neighboring watersheds, land management activities and road development in this watershed probably have not significantly affected streamflow, since areas with far less wilderness have been attributed with relatively no effects.

The USGS measured streamflow in Moss Creek occasionally between December 1964 and October 1967, but did not denote whether diversions occurred upstream of this site. There is only one water right in the Moss Creek watershed, and the water right certificate was established for irrigation purposes allowing a maximum of 1.5 cfs to be diverted. The gage record shows Moss Creek going dry in the summer and early fall. This water right probably was not used during these months. Any diversions during snowmelt runoff months would have minimal effect on total monthly flow. Since the majority of the Moss Creek drainage has been unaltered by diversions or land management activities, the few gaged streamflow measurements available are considered natural.

The USGS gaged streamflow measurements between December 1964 and October 1967 were used to develop total monthly streamflow estimates by rescaling Varney Creek and South Fork Rogue River (S.F. Rogue + S.F. Power Canal near Prospect) gaged records. The USGS has developed monthly total flow estimates between October 1964 and September 1967 (Hubbard, 1970). For the other watersheds where estimates had already been developed by the USGS (Rock Creek and Fourmile Creek), the redevelopment completed showed very similar results in the majority of months.

One general equation that accounts for low and high flows was developed and used to generate the synthetic time series for Moss Creek. Sufficient data were not available to create month-specific equations. A season-specific equation was attempted to account for spring runoff, but no further calibration was found from this equation.

The inadequacies of this time series are analogous to those of Nannie Creek. Despite the inability to calibrate these numbers with more accuracy, the monthly total estimates used for correlations exhibit sufficient variability to represent natural streamflow in Moss Creek. Once again, the occurrence of a significant flood event and observations of Moss Creek being dry represent the full extent of streamflow variation expected in a 50-year period. Thus, even though the synthetic time series for Moss Creek was not based on numerous data points, a representative time series was generated by capturing sufficient variability.

Exceptions to Standard Methodology

Not all watersheds in the Wood River Valley have the same basin characteristics. Several watersheds have unique geology or dominant flow regimes. One particular watershed has streamflow data available, but the data represent an altered state due to the presence of a dam and diversions out of the reservoir. The standard methodology for developing a natural time series is inadequate for such watersheds.

To quantify the natural inflow to Upper Klamath Lake from these basins, alterations to the standard methodology were made. Watersheds that had unique geology, Annie and Sun Creeks, were developed using streamflow along with precipitation data. Denny Creek was developed in a similar fashion since the flow regime is dominated by winter precipitation rather than snowmelt runoff, unlike most Wood River Valley basins. Finally, the Fourmile Creek natural time series was developed by naturalizing the available streamflow measurements before proceeding with a more standard process as previously described. A detailed description of each uniquely addressed watershed follows.

<u>Annie Creek</u> – at gage south of Crater Lake National Park / Winema National Forest boundary

The geology of the Cascade Range varies within the Wood River Valley. The ancient volcano Mount Mazama formed the current day caldera of Crater Lake, which was formed between 4,000-7,000 years ago. Mount Mazama was a volcano of great altitude, with a maximum elevation of more than 12,000 feet above sea level. The steep slopes of Crater Lake show abundant evidence of large glaciers, particularly on the south side. The south valleys are U-shaped and have the smooth parallel side characteristic of glacial channels. During the final eruptions of Mount Mazama, glowing pumice and scoria lava flowed down the south side into the Annie Creek and Sun Creek drainages (Frank et al, 1969; Williams, 1956). Because the geology of these watersheds is uniquely different compared to the other Wood River Valley drainages, the standard process for quantifying natural streamflows was inadequate.

The Annie Creek drainage is 28.5 mi^2 in area and drains south, with headwaters located on the south side of Crater Lake. The streamflow hydrograph for Annie Creek is characterized by spring-fed flow in the autumn and winter and snowmelt runoff driven spring and summer time flows. The spring flow dominating this watershed may even have originated in Crater Lake. The extended period of record for Annie Spring, near the Crater Lake National Park Headquarters, was invaluable in developing a synthetic time series for Annie Creek.

The USGS has collected streamflow gaged records at Annie Spring since June 1977. Similarly, the USFS has maintained a gage at the National Park/National Forest boundary since October 1993. Some water is diverted at the Crater Lake National Park Headquarters for residential uses, and these diversions are quantified and available in the USGS Water Resources Data Publications for Oregon. From the available gaged data, a natural synthetic time series was initiated for Annie Creek by performing month-specific linear correlation analyses that had been modified for the line of minimum absolute deviation or a generally similar fitted line.

These month-specific correlations were created between Annie Creek data and the naturalized Annie Spring data. The Annie Creek data were not naturalized, per se, before correlating with Annie Spring, but the upstream diversions were expected to have inconsequential effect on the Annie Creek gage, which represents flow resulting from a large drainage area. There are no other diversions above the Annie Creek gage location, as the intermediary land is part of Crater Lake National Park. The correlations for most months exhibited r^2 values around 0.90, with March and November exhibiting the worst r^2 values around

0.60. This correlation analysis extended the Annie Creek record back to June 1977, but estimates needed to be made back to 1947.

Several techniques were attempted to develop the earlier years. Relationships between Annie Spring and Annie Creek data with other nearby gages unfortunately exhibited no correlation. Luckily, near the crest of Crater Lake within the Annie Creek drainage, the U.S. Department of Interior National Park Service (NPS) has collected extensive temperature and precipitation data at the Carter Lake National Park Headquarters. The Crater Lake temperature and precipitation gage data extends unbroken back beyond 1946, and data is still being collected today. These data were found to be very valuable for correlations in lieu of a gaged watershed with similar geologic features.

Crater Lake precipitation and temperature data were used to develop the early years of the synthetic time series for Annie Creek. Correlations were completed against Annie Creek monthly streamflow totals. Even though the Annie Creek record was extended back to1977, the 1977-1992 streamflow estimates were not considered sufficiently accurate to be used in correlations against weather data. Annie Creek gaged streamflow data were obtained for water year 2002 and were included in the remaining correlation analyses. Therefore, only 10 years of gaged streamflow data were available for developing the initial years of the time series.

Crater Lake temperature data showed definite trends as to which month the peak spring runoff had occurred. The peak runoff month for 1948-1976 was determined by employing a monthly average temperature rule. This rule generally defined the month with the largest spring runoff as being the second spring month with average temperature above 33°F, with a few caveats. This rule provided the backbone for estimating the early years, when coupled with the ability to estimate total discharge in the peak month.

The available weather data were used to develop peak monthly total flow for 1948-1976. A good correlation (r^2 value of 0.98) was found between lagged total winter precipitation and total streamflow in the peak runoff month. Total winter precipitation was defined as total precipitation between the months when average temperature fell below 33°F through the peak runoff month. The winter precipitation totals were lagged over 5 years, since the flow in Annie Creek is not directly related to only the previous winter. The accumulation of snow and rain in Crater Lake recharges ground water aquifers, which provide streamflow to Annie Creek. The movement of subsurface water can be quite slow, depending on the regional geology, and can affect ground water discharge to the surface for several years. The lagging of winter precipitation totals mimics the combination of direct snowmelt runoff from that winter's total precipitation plus the reappearance of ground water in Annie Creek.

The baseflow months of Annie Creek are very distinctive. Streamflow in the late summer and early autumn months declined at a similar rate every year. Since incidental streamflow measurements in August, September, and early October were available for 1949 through 1973, the baseflow level could be estimated for each year.

By having the peak runoff and baseflow estimates, the intermediate months could be estimated. Month-to-month correlations were developed where the flow in one month could define the total flow in the following month when combined with precipitation data. Equations were developed to generally define the following month, where relationships between gaged flows and precipitation qualified whether a month-to-month discharge equation or a precipitation driven equation should be used to estimate monthly total flow. Precipitation driven equations were used mostly in the autumn months, before the average monthly temperature fell below 33 F, and were not employed in sub-freezing months. Of course, rain-on-snow events occur in the region and needed to be addressed.

The effects of winter storms and rain-on-snow events were investigated. A significant flood event occurred December 24, 1996-January 3, 1997, during which the USFS maintained a daily recording stream gage. Assuming the gage did not malfunction, which does not seem likely from the peaking evident in gaged daily streamflow data, then apparently Annie Creek does not experience as severe floods as observed elsewhere. Large increases in monthly total flow that were observed by nearby gages were not seen in the Annie Creek gage. The Rogue River above Prospect monthly total flow increased 189% from November to

December in 1996. Similarly, the Sevenmile Creek near Fort Klamath total monthly flow increase by 129%. The total monthly flow in Annie Creek fell by about 1% between November and December 1996. Flows in Annie Creek generated by this winter storm were within normal winter streamflow variation and did not exceed typical peaks of spring runoff flows. Despite the similarly shaped daily streamflow hydrographs, the effect of this rain-on-snow event on Annie Creek monthly total streamflow was minimal compared to other nearby watersheds.

The winter storm of December 29, 1995-January 1, 1996 was also captured by Annie Creek streamflow records. Monthly total streamflow increased from November to December in the Rogue River above prospect and Sevenmile Creek near Fort Klamath gaged records by 317% and 318%, respectively. Annie Creek experienced a 165% increase in monthly total flow. The effects of this storm on Annie Creek are more prevalent than those from the December 1996 event, but estimating these effects without streamflow measurements would be highly data intensive and not necessarily accurate. Antecedent snow pack conditions would need to be known, along with the precipitation type (rain or snow) and snow-line elevation of each storm to attempt incorporating the dramatic effects of winter storms. Therefore, the effects of rain-on-snow events were not incorporated into the monthly synthetic time series, with one exception.

The effects of the December 1964 storm were included in the Annie Creek synthetic record. Monthly total estimates were developed for this storm by comparing the effects of the December 1995 storm on the Rogue River above Prospect gaged record and the Annie Creek record. This particular storm was estimated and included because of the large affect this storm had on streamflow across the Wood River Valley. Inclusion of these estimates was an attempt to further calibrate the synthetic time series for Annie Creek.

Additional instantaneous streamflow measurements were available to estimate streamflow between May 1991 and September 1992. Work related to a report on water quality of Wood River subbasins (Hathaway et al, 1993; Hathaway, 2003) provided streamflow measurements in Annie and Sun Creek. The USGS also collected several instantaneous flow measurements at the same Annie Creek location during that time period. When these measurements were combined, streamflow had been measured at least once a month between May and October 1991 and between March and November 1992. The estimates found using these miscellaneous flow measurements were highly similar to those found using the correlations against Annie Spring. The monthly total estimates generated from miscellaneous flow measurements were considered more accurate than the Annie Spring generated estimates and thus were used in the final synthetic file.

Development of the natural synthetic time series for Annie Creek took extensive time to gather available data and complete correlation analyses. Also, all data used in this development were measured within the Annie Creek basin. In the end, the natural synthetic record for Annie Creek is believed to be sufficiently representative, despite the inability to predict the effects of rain-on-snow events. This synthetic record provided the basis for the Sun Creek watershed, located immediately to the east, and was used with ample confidence in its reliability.

<u>Sun Creek</u> – at Crater Lake National Park/ Sun Pass State Forest boundary

All land upstream of the gage location on Sun Creek is protected wilderness within Crater National Park. There are no diversions from the stream within the park, and the contributing drainage area for the gage is 11.1 mi^2. The same glacial and volcanic processes that formed the geology of Annie Creek occurred in Sun Creek. Due to the similar geology, the streamflow hydrograph that occurs in Sun Creek is likely to be more similar to Annie Creek than any other stream. Hence, the Annie Creek synthetic time series provided the basis for the estimated natural streamflow of Sun Creek.

Very little streamflow information is available for Sun Creek. Hathaway and Todd (1993) collected several years of miscellaneous streamflow measurements on Annie Creek and Sun Creek. From the concurrent measurements at the most upstream and natural sites, highly similar flows were observed in the two streams. From these data, the flow in Sun Creek was estimated to be 25% of the magnitude of Annie Creek flow. To create a synthetic time series for Sun Creek, the Annie Creek time series was rescaled by 25.17%

based on concurrent gaged data. Total monthly streamflow estimates were generated for May -October 1991 and March – November 1992 using the miscellaneous streamflow measurements from Hathaway and Todd. In most cases, these estimates were used in place of the estimates generated by rescaling the synthetic time series for Annie Creek, since these estimates were considered more accurate due to their basis of actual gaged Sun Creek data.

Fourmile Creek – at Upper Klamath Lake

Fourmile Creek is located on the east side of the Wood River Valley, immediately south of Rock Creek. The entire Fourmile Creek watershed drains approximately 105 mi^2, and flows directly into the marshlands near Pelican Bay of Upper Klamath Lake. There are three major subwatersheds known as Fourmile Creek, Fourmile Creek above Seldom Creek, and Lost Creek. The Seldom Creek subwatershed contains Lake of the Woods and only releases water into Fourmile Creek intermittently. Of the entire watershed area, 32% is contained within wilderness areas of the Winema and Rogue River National Forests and has remained in a relatively unaltered state, 2% is private land, and the remaining 66% is non-wilderness National Forest Land.

The water and land of Fourmile Creek watershed has been actively managed during the last century. Timber harvesting in the drainage began around 1900. The south and southwest slopes of Pelican Butte, Fourmile Flat area, and the lower Lost Creek drainage were harvested in the early 1900s, and harvest activities were greatest in the 1960s, when partial timber removal occurred on at least 7.5 mi^2. Timber harvesting has continued since then, but to a lesser extent. Since canopy closure has not been significantly reduced in the Fourmile Creek watershed, it is considered unlikely that timber harvesting has had a measurable affect on streamflow (USDA, 1996).

On the other hand, a definite change in streamflow variability has occurred due to the presence of Fourmile Dam. Fourmile Creek above Seldom Creek contains Fourmile Lake, which is actively managed by operation of Fourmile Dam. Not only is water held back by the dam, water is diverted out of Fourmile Lake by Cascade Canal, which transports the water out of the Fourmile and Klamath basins. Water from Cascade Canal is carried west over the Cascade Range into Rogue River basin and is discharged into North Fork Little Butte Creek upstream from Fish Lake.

Originally, Cascade Canal was composed of earth and rock. Upgrades were made in 1915 to build the concrete structure still in use today. Upon completion of Fourmile Dam in October 1922, the capacity of the natural lake was increased, and the flow regime in Fourmile Creek stabilized to present conditions.

Within the last few years, no active releases to Fourmile Creek have been made. AN assumption is that the water from Fourmile Lake was only directly connected with Fourmile Creek if the spillway was crested. In the past, flash boards have been used on Fourmile Dam to increase the capacity. Therefore, only very large flood waters were assumed to contribute directly to flow in Fourmile Creek.

Streamflow in Fourmile Creek may still have been replenished by water retained behind Fourmile Dam. The Fourmile Lake/Dam system is anticipated to recharge of surficial aquifers that contribute to flow downstream in Fourmile Creek. This seepage could not be quantified from available stream gage records, and thus was considered to be minimal for lack of better data.

The Fourmile Dam and Cascade Canal regulations have affected the timing, duration and quantity of streamflow in Fourmile Creek by disconnecting a large headwater area. To estimate the natural streamflow of the Fourmile Creek watershed, the total flow captured and diverted from this headwater area needed to be quantified and added to the streamflow generated by the remaining connected area. Using reservoir content and Cascade Canal diversion data, the inflow to Fourmile Lake was estimated. These data were then added to the available gaged records in order to create natural monthly streamflow totals.

The streamflow records for Fourmile Creek are available from the USGS and USFS. Monthly total streamflow estimates were made from the USFS data, which constituted miscellaneous instantaneous streamflow measurements in the spring and summers between April 1992 and May 1997. The USFS gage site is located in a narrow valley ¾ mile above the Seldom Creek confluence, and this site includes all water produced by the upstream watershed less the area above Fourmile Lake. Alternatively, the USGS maintained a daily recording streamflow gage on Fourmile Creek near Rocky Point (below Varney Creek) between October 1964 and September 1967. The measurement location of the USGS gage is situated in an alluvial valley bottom, most likely with lacustrine deposits. Some water produced by the Fourmile Creek watershed has likely already gone subsurface at this location. Neither gage location is perfect for use in developing a larger synthetic time series, but the available gage data still proved to be highly beneficial.

The USFS data accurately depict the water produced above Seldom Creek minus the Fourmile Lake watershed. Without any gage information for Seldom Creek, assumptions must be made about the additional water generated by this area. Since Seldom Creek is noted to only provide flow to Fourmile Creek intermittently, which is typically very large flows not seen in the early 1990s, Seldom Creek was assumed to not directly connect to Fourmile Creek for the months estimated in the 1990s. Since the majority of water in Fourmile Creek originates from springs in the upper headwater areas, the lower portion of the watershed is considered to produce minimal flow in comparison to the upper. The monthly total estimates generated from the USFS measurements were considered to be representative of what is produced by Fourmile Creek without the Fourmile Lake and Varney Creek watersheds.

During the 1960s daily gage records, the USGS collected daily streamflow measurements on Varney Creek and Fourmile Creek. These gages are both recorded during the same time period in the mid 1960s, between October 1964 and September 1967. These gages clearly illustrate how much water seeps subsurface on the alluvial valley floor. The flow in Varney Creek was measured just upstream of the confluence with Fourmile Creek. For several months, Varney Creek flow measured between 20-100 ac-ft, while the Fourmile Creek gage recorded no flow at all. By comparing the two records, losses in Varney Creek along the valley floor were estimated. In July 1965, the Varney Creek gage measured 113 ac-ft in total flow, and the Fourmile Creek gage measured only 1 ac-ft. Assuming Fourmile Creek above Varney Creek was otherwise dry that month, the losses in Varney Creek were estimated to be around 100 ac-ft per month. This information aided in generating natural flow estimates for the 1990s.

Monthly streamflow totals were naturalized by adding water excluded from gaged records to the gaged records. In the 1990s, the Varney Creek monthly total streamflow was estimated from USFS miscellaneous streamflow measurements. These totals, minus the estimated Varney Creek losses, were added to the Fourmile Creek monthly flow estimates. The remaining piece needed to naturalize streamflow was the water produced by the Fourmile Lake watershed.

The inflow to Fourmile Lake was estimated as monthly change in reservoir storage plus outflow. Since outflow to Fourmile Creek has not occurred over the last few years, and no documented outflows have been recorded, the only outflows included are those diverted into Cascade Canal. Diversion records for Cascade Canal out of Fourmile Lake are available from USBR back to June 1992. Prior to that 1992, the USGS maintained records for Cascade canal near Fourmile Lake intermittently since 1923. These diversions were added to change in reservoir storage, which were generated from end-of-month (EOM) reservoir contents. Reservoir EOM data have been collected intermittently for Fourmile Lake since 1923. A continuous record begins in September 1991 and is available through 2003. After adding diversions to change in storage, several resultant “inflow” values in the winter and early spring were still negative. These values are likely the result of losses to groundwater and evaporation.

In order to accurately naturalize gaged streamflow, negative numbers found by adding Cascade Canal diversions to the change in reservoir storage were replaced by zero values. When otherwise naturalizing streamflow after a dam is present, the evaporation losses would be estimated and added to the diversions and change in storage. Evaporation losses off Fourmile Lake were estimated to average 320 ac-ft per month, as long as evaporation rates are similar to those for Upper Klamath Lake. These evaporation losses were not used to naturalize lake inflows, because Fourmile Lake is a natural lake. Documentation of the lake’s surface area prior to dam construction could not be found, so the post-dam evaporation losses were assumed to be similar to natural values. In the end, natural lake inflows were considered relatively equal to the change in Fourmile Lake storage plus diversions.

Natural flows were developed for Fourmile Creek during two time periods. To naturalize gaged data for Fourmile Creek, the estimated inflow to Fourmile Lake was added to monthly streamflow totals between October 1964 and September 1967 and estimated monthly totals between April 1992 and July 1996. Varney Creek flows were already reflected in the 1964-67 Fourmile gaged data, but the 1992-96 estimates did not reflect this additional water. Miscellaneous flow measurements on Varney Creek were collected by the USFS between April 1992 and July 1996, which enabled the development of monthly total estimates for Varney Creek. These estimates were generated by rescaling South Fork Rogue River (S.F. Rogue + S.F. Power Canal near Prospect) and Rogue River above Prospect gages based on concurrent measurements. The Varney Creek monthly flow estimates were decreased to reflect channel losses, which were estimated from the 1964-67 data, and then added to the 1992-1996 flows for Fourmile Creek. In total, natural monthly streamflow estimates for both the 1964-67 and 1992-96 time periods reflected the Varney Creek drainage, the Fourmile Lake headwaters, and the water produced by the in-between area.

The natural flow estimates from the 1990s still differ slightly from the 1960s data. The gage location of the 1960s Fourmile Creek data suggests some water was probably lost to ground water prior to being gaged near Rocky Point. Conversely, the gage location of the 1990s data reflects the water produced by the watershed more accurately for that time period. The flow of ground water through the alluvial valley bottom is likely to accrue towards Upper Klamath Lake even though some water may go subsurface upstream from the USGS gage location. In order to answer the ultimate question regarding how much water from Fourmile Creek would have provided inflow to the lake under natural conditions, the 1960s data were acknowledged to slightly underestimate the natural inflow to the lake from Fourmile Creek. The 1990s data were accepted as being more representative.

The monthly total natural flow estimates were then used to develop correlation equations with South Fork of the Rogue River. The Rogue River above Prospect was considered for correlation as well, but the South Fork Rogue River proved to reproduce expected values more accurately. This discovery is not surprising, since South Fork Rogue River lies closer to Fourmile Creek, immediately to the northwest with a common watershed boundary, and has similar geology and topography.

Correlation equations were developed using monthly natural streamflow totals. A general equation incorporating all available data was generated to represent most months, while some spring and summer months were further calibrated with season or month-specific equations. The flood event of December 1964-January 1965 and several subsequent runoff months were not included in these correlations, since the gaged streamflow values for Fourmile Creek during and after that event seem uncharacteristic for watersheds in the area. The cause for this departure can be attributed to either partial spill releases from Fourmile Lake, the reconnection of Seldom Creek during an extremely high flow event, or both.

The Fourmile Creek synthetic time series should be considered a rough estimate. Despite efforts to naturalize inflow to Fourmile Lake, the error incorporated in these data could not be determined. The derived natural flows for Fourmile Creek may be considered representative, since they reflect actual stream variability including zero values and significantly high flows. Although the extremely large flow events may not be represented with as much accuracy, the typical flows are effectively captured since the correlation equations used were based on typical flow regimes in two separate time periods.

<u>Denny Creek</u> – at Upper Klamath Lake

Denny Creek is located near the south end of Upper Klamath Lake and flows into Ball Bay. The watershed drains approximately 51 mi^2 and contains Aspen Lake. Only 17% of this watershed is within USFS land, with the majority within the Mountain Lakes Wilderness area. The remaining watershed area seems to be privately own, most likely by an individual owner. Despite similarities in geology between Denny Creek and adjacent watersheds, Denny Creek differs from most Wood River Valley watersheds in that the flow regime is not dominated by snowmelt runoff.

The streamflow hydrograph for Denny Creek is driven by the release of water from springs and winter precipitation, as seen in the peaking during winter months. Less snow accumulates in the headwaters of Denny Creek due to lower elevations. Because of this different flow regime, generating the synthetic natural time series for Denny Creek from a streamflow gage that was driven by snowmelt runoff was considered inappropriate. Streamflow gages for the area were analyzed for their dependence on winter precipitation, but no available gages were similar to Denny Creek. For lack of better data, the precipitation gage at Rocky Point was analyzed for relationships to streamflow in Denny Creek.

Instantaneous flow measurements were collected on Denny Creek by the USGS between September 1964 and October 1967. The USGS did not document whether any diversions occurred upstream of these measurements, so no diversions were assumed to have occurred. The Oregon Water Resources website shows one point of diversion upstream of the gage site, but the water right certificate connected to the point did not discuss or allow a diversion out of Denny Creek. This point of diversion was considered an error.

The USGS developed monthly total estimates for this time period (Hubbard, 1970), but these values were compared to redeveloped values to ensure accuracy. Redevelopment of monthly total streamflow estimates was completed using Varney Creek and Red Blanket Creek gaged data, and the results differed greatly from the USGS estimates, especially in low flow or baseflow months. The USGS estimates were considerably larger for these months. The redeveloped estimates were considered more accurate and were used in developing correlations to monthly precipitation data.

Precipitation is not considered to directly affect the flow in each month. The transit time over 58 mi^2 to the Denny Creek gage can be considerable, and groundwater recharge and resurfacing does not occur immediately. To represent these flow-affecting processes, precipitation totals were lagged over several months, with different percentages applied to each month, to find the effective precipitation value for each month. Ultimately, the best correlation to streamflow was found by lagging precipitation data 6 months, with 30% reaching the gage concurrently and the remaining 70% being lagged over the next 6 months. This effective percentage decreases each month, so the effective precipitation for each month is related to the precipitation from the previous 6 months. For example, the effective precipitation value for June is 30% of June's total precipitation, 21% of the May's precipitation, 15% of April's precipitation, and so on.

Correlations to streamflow were found between monthly effective precipitation values and monthly total streamflow estimates found between 1964 and 1967. Least-squares equations were found for effective precipitation values above and below 2.5 inches. The majority of effective precipitation values were below 2.5 inches, which was captured by a curvilinear correlation that recovered 86% of variability (r^2 value of 0.86).

The synthetic time series developed for Denny Creek is unique in that it depends solely on relationships between effective precipitation and streamflow between 1964 and 1967. The final time series sufficiently represents the streamflow in Denny Creek, since low-flow and extremely high flows were available in the gaged streamflow data, but this time series is not necessarily exact. More gaged information for Denny Creek would allow further correlation analysis to be completed. Also, collection of gage information on another nearby stream dominated by winter precipitation might also prove invaluable. Ultimately, the synthetic natural time series developed is representative for Denny Creek and adequately addresses the magnitude of inflow Denny Creek provides to Upper Klamath Lake.

Evaluation of Wood River and Crooked Creek –

Three primary elements must be considered in the evaluation of the Wood River and Crooked Creek. First of these requires the determination of the inflow from Annie Creek and Sun Creek, the sum of which form the headwater of Wood River. Second, ground-water accrual to the Wood River and Crooked Creek must be determined. For the Wood River, ground water is derived from Wood River Springs, also at the head of Wood River, and from ground-water fed Fort Creek, a tributary to the Wood River that heads on the margin of the valley floor to the east of Fort Klamath. Crooked Creek presents similarities to Fort Creek and derives its flow from many springs and seeps along the eastern margin of Wood River Valley from southeast of Fort Klamath near the Klamath State Fish Hatchery, south to the Klamath Agency. Third, a riparian marsh system was attendant to each of these streams, and caused incurred losses to flow of these streams. Such marshlands, therefore, required assessment to determine the magnitude of these losses.

Wood River –

Evaluation of the Wood River included a comprehensive survey of published miscellaneous flow measurements made by the USGS from approximately 1900 to generally about 1970. Although some later measurements were used, records prior to the early 1970s present the best opportunity to capture measured flows that are unaffected by accelerated cultural development. Flow measurements considered included those made at Fort Klamath, and elsewhere above this location, generally during the winter season. Some aspects of the flow were developed from an analysis of the gaged record at Fort Klamath from 1914 to 1936. This flow record contained several missing years and the gage was discontinued in 1936. These measurements were compiled, sorted by month of occurrence, and evaluated. Measurements that had been affected by diversions and other upstream uses were culled from consideration. Based upon measurements that were considered, a representative, monthly-basis estimate was developed of natural spring fed inflow and ground-water accrual that is tributary to the Wood River above its confluence with Fort Creek. The indicated average natural flow of Wood River Springs was about 293 cfs. From the springs to the gage at Fort Klamath, there is sparse information that the estimated additional accrual averaged about 56 cfs. However, there is reason to suspect this accrual was not by natural ground-water inflow, but by irrigation return flows that were draining into the stream.

The evaluation of Fort Creek was similarly undertaken to that of the Wood River. Miscellaneous flow measurements for Fort Creek, however, were somewhat more comprehensive than those considered for the Wood River. These measurements were compiled, sorted by month of occurrence, and representative measurements unaffected by diversions and other upstream uses were considered in developing an assessment of natural ground-water conditions for Fort Creek. The derived estimate of spring fed and ground-water inflow that is tributary to Fort Creek, and hence, to the Wood River, indicated the natural spring-flow of Fort Creek was about 89 cfs. In each case, whether for the Wood River, or for Fort Creek, the indicated locations for the gage records, and each of the miscellaneous measurements, was map-posted, or checked.

Evaluation of the stream-associated riparian system was based on a detailed photo-interpretive assessment of color-infrared ortho-photography that had been flown in July, 2002, and assembled by the Bureau of Reclamation (12-208-1000). This imagery covered approximately the eastern third of the Wood River Valley. From this imagery, and 9 by 9 inch prints of the acquired color infrared photography (BR-KLA-14), the trace of the previously existing, stream-associated, natural riparian area was delineated. Because the color infrared photography was provided as approximately 1:31 000 scale prints, and as an ortho-photo image mosaic scaled at 1:40 000 and at 1:10 000, these delineated areas were collectively posted on 7.5 minute quadrangle overlays scale reduced at 1:40 000. These overlays were then reduced to 1:63 360 and planimtered to determine the land-surface area of the riparian marshland affecting natural flow of the Wood River and Crooked Creek. The assessed areas of these riparian marshland areas were of those exclusive to the lake wetland marsh attendant to Upper Klamath Lake.

The monthly average flows indicated for ground-water accrual to Wood River, inclusive of Fort Creek, were added to the estimated natural inflow from Annie Creek and Sun Creek, to provide the total estimated inflow to the Wood River system. Losses determined for the associated riparian areas were subtracted from this inflow, thereby providing an estimate of inflow to Upper Klamath Lake from the Wood River. For the period of interest, 1949 to 2000, this inflow was estimated to average about 420 cfs.

Crooked Creek –

The evaluation of Crooked Creek followed the same general approach taken for the Wood River. Crooked Creek is indicated to be a tributary of the Wood River, yet there is evidence this was not always so. Although the Wood River has a well-established channel along the eastern margin of the wetland marsh at the northern end of Agency Lake, and extension of Upper Klamath Lake, there apparently were times when the Wood River was lost in the wetland area, and Crooked Creek was not directly tributary to the Wood River. For pre-development conditions considered herein, Crooked Creek may have entered the Wood River along the eastern margin of the wetland marsh area just above the mouth of the Wood River at Agency Lake. The present-day channel of Wood River has been channelized and straightened generally along the pre-existing alignment the stream had under natural conditions.

Above its confluence with the Wood River, Crooked Creek flows in a tightly meandering channel along the eastern margin of the valley floor. Because there is virtually no contributing watershed area, flow in Crooked Creek is limited to flow from several springs and ground-water seepage that arises along east bounding wall of the Wood River Valley. The accumulation of this flow is initiated about 1.7 miles southeast of Fort Klamath. These springs increasingly add to the flow of Crooked Creek. Records indicate various names for some of these springs, of which one or two were given inconsistent reference. However, for most miscellaneous flow measurements that are published for Crooked Creek, the indicated locations were sufficiently distinct that a representative assessment could be accomplished and the locations of named springs determined along the stream.

Miscellaneous flow measurements were only considered for the period from 1900 to 1960 to eliminate, or restrict, the effect from development. Although diversions occur from Crooked Creek, notes in many of the records indicated if the measurements were made above, or below, these diversions, and very occasionally noted the amount that was being diverted. These measurements were compiled, sorted by month, and trends due to development were evaluated. Hence, a water-budget could be established based on measured spring flow and ground-water seepage that accrued to the stream. Results of the analysis indicate that a representative estimate for the undepleted ground-water influx into Crooked Creek was about 95 cfs, but may have been as high as 103 cfs.

Crooked Creek also had an associated riparian marshland like that along the Wood River. Evaluation of this riparian marsh was completed just as that for the Wood River and Fort Creek. This riparian marsh causes a loss to the flow of Crooked Creek before inflow to Upper Klamath Lake. For the period of interest, 1949 to 2000, average natural flow of Crooked Creek, inclusive of this natural loss, was indicated to be about 94 cfs.

Evaluation of Sprague and Williamson Rivers –

Restoring to natural flow the gaged flow of the Sprague and Williamson Rivers requires an assessment of lands irrigated by diversions of streamflow, and of reclaimed natural marshlands. Net consumptive uses incurred by diversions to irrigated lands have depleted streamflow and such depletions must be added back to gaged flow. Consumptive uses that would have been incurred by reclaimed natural marshlands would have caused a loss in natural flow, and must be subtracted from the derived result. The water budget for natural flow at the gage is straightforward:

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

Of usual consequence to this type of water budget would be irrigation return flows that are delayed in returning to the stream. Because the Sprague and Williamson Rivers do not have well developed and transmissive valley fill alluvial aquifers, and because most of the irrigation diversions from these streams irrigate land that is in proximity to the stream, irrigation return flows may be considered due to field runoff from flood irrigation and not drainage to the stream of irrigation percolation losses that recharge a ground-water reservoir hydraulically connected to the stream. As such, these return flows are not delayed significantly in returning to the stream after the application of diverted water to the irrigated field. This water, therefore, is reasonably accounted at the gage and would have been considered a factor in diversion from the stream and irrigation of crops if otherwise delayed by ground-water drainage to the stream. 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. For marshland, this same definition applies. Marshland net evapotranspiration is simply the potential evapotranspiration that may occur from the marsh less effective precipitation. Because not all precipitation is sufficient to offset potential evapotranspiration, only the part that is effective in doing so is considered. These uses by crops and marshes were calculated using a modified SCS Blaney-Criddle model. Meteorological data from several nearby data-collection platforms 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 reconstruction of missing values to gain a complete time series for the selected period of analysis.

Assessment of irrigated lands 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 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 overlayed for each coverage type to determine the affected natural marshland area for the natural loss assessment. Affected and non-affected marshlands were also mapped based on indications shown on the 15 minute quadrangles. The areas of affected marshlands were planimetered, as these were the reclaimed marshland areas, and the total of these areas noted for each individual quadrangle where marshland coverage had been mapped.

Watershed conditions were also evaluated using a mosaic-composite of individual 15 minute digital ortho-photo quads reproduced at a scale of 1:63 360. Four individual yet adjacent 7.5 minute ortho-photo quad frames were used in developing each these 15 minute ortho-photo quads. 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 randomized, smaller cut areas, which would indicate this activity has had minimal impact to hydrologic response of the watershed. These examinations were completed primarily for the Sprague River watershed.

The present-day discharges of both the Sprague and Williamson Rivers are measured by gaging stations having complete records beginning well before the period of interest. Given the completeness in these gaging records, an assessment of watershed areas or an evaluation of discharges for individual subwatersheds was not required to determine the natural flows. The evaluation, therefore, was limited to completing an assessment of factors that would have changed streamflow from that occurring under natural flow conditions.

The Sprague River –

The most significant changes affecting natural flow of the Sprague relate to the development of irrigated croplands and the reclamation of marshlands for irrigation. 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 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 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.

The Williamson River –

The evaluation of the Williamson River required consideration of several factors that are consequential to present-day gaged flows. The irrigated area of interest for the Williamson is for pastureland that lies in the upper part of the watershed above Klamath Marsh. Field surveys indicate that pastureland development in this area has not effected significant changes to the marshland character associated with the stream. However, below this irrigated pastureland the natural extent of Klamath Marsh has changed as the perimeter of the marsh, especially within its lower segment, is apparently somewhat different under current conditions than noted for predevelopment conditions. In addition, diversion of flow into the Modoc Canal from the Sprague below the Sprague River gage near Chiloquin depletes the inflow of the Sprague to the Williamson. Because the principal gage for the Williamson lies below the confluence with the Sprague, these diversions by the Modoc are a depletion to the gaged flow of the Williamson. Therefore, the estimated diversion requirement of the Modoc was added to the gaged flow of the Williamson, and the current gaged flow of the Sprague subtracted to restore the present-day flow of the Williamson to a pseudo-gage, or node, above its confluence with the Sprague. Within the reach of Williamson from below Klamath Marsh to the confluence with the Sprague, there has been little apparent change to the natural character of the stream.

The evaluation of irrigated pastureland depletions and losses from Klamath Marsh in the upper Williamson was based on restored meteorological data given for the Chemult station, which is in the vicinity of these features and at an elevation similar to these areas. Although a limited irrigated area in the upper Williamson is closer to the Sprague River station than the Chemult station, data for Chemult was seen as generally more representative in this case due to the consistency of weather patterns and elevation with that of the area being considered given the somewhat lower elevation of the Sprague River station.

The difference between predevelopment and present-day areas for Klamath Marsh has determined the net change in marshland area that has affected part of the natural flow of the Williamson. The present-day area of Klamath Marsh was provided by OWRD. Predevelopment area of the marsh was determined from an extract of the Chiloquin 1:125 000 scale 30 minute sheet taken from the 1906 compilation map published by the USRS. The 1906 map, as mentioned elsewhere in this report, was published as a 1:250 000 scale compilation of several adjoining 1:125 000 scale 30 minute sheets mapped by the USGS in the mid 1880s using plane-table methods. A portion of the predevelopment marsh was also determined from the 1935 Chemult 1:125 000 scale 30 minute quadrangle that is published by the USGS. Although field mapping of this quadrangle was also completed using plane-table methods, the accuracy and quality of the land-surface representation is superior to that shown for the adjoining area on the 1906 compilation sheet. Predevelopment marshland areas were posted on 1:62 500 scale 15 minute quadrangles of Klamath Marsh and Lenz, that had been scale-reduced to 1:125 000. These present-day 15 minute quadrangles were published by the USGS in 1957. The lower segment of the marsh that is generally west and south of Wildhorse Ridge was interpretively delineated. The upper segment of the marsh in the area generally north of Wildhorse Ridge, was delineated as the marshland area appearing on the scale reduced Klamath Marsh quadrangle, and as posted directly from the marshland area indicated on the 1935 Chemult sheet. The appearance of this upper segment shows apparently little change from its presumed predevelopment area. However, registration of land surface features and of the marshland areas on the more recent sheets with those on the earlier USRS sheet shows the existence of mapping errors on the older sheet that are difficult to reconcile. Some of the marshland indicated on the USRS sheet was not included for this reason. The evident impression of the landscape, however, is interpretively assessable from the older USRS sheet and the appearance of the marshland shown on the present-day USGS sheets was deemed representative of these earlier mapped conditions.

Evaluation of depletions to the Williamson by diversions of the Modoc Canal was completed by using restored meteorological data for Chiloquin. This depletion is to the Williamson gage near Chiloquin and is attributable solely to the diversion taken by the Modoc for use on irrigated lands below the gage. Therefore, the gage for the Williamson was restored to its present-day flow above the Sprague without the affect of this depletion. This was accomplished 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. This restored present-day flow for the Williamson above the Sprague was used for determination of natural flow for the Williamson. To determine the undepleted natural flow at this location, the total net consumptive use for irrigated pastureland in the upper Williamson was added to this flow record. Similarly, because reclaimed natural marshland would have affected the flow of the Williamson under natural conditions, the loss determined by the net consumptive use of the reclaimed marsh area was subtracted from the resulting flow that had been determined for the Williamson.

Evaluation of the natural Upper Klamath Lake –

To evaluate the natural condition of Upper Klamath Lake, materials documenting the frontier condition of the landscape were reviewed. 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 US Army, and the survey of western lands by the USGS. Earliest of these regards the report in which notes of Lt. R. S. Williamson are compiled describing the condition of the frontier that he saw in 1855. Although information by Williamson is generally of incidental interest, certain elements in the description of the landscape provide a view that has assisted in the interpretive aspects giving definition to the natural lake, and in visualizing the landscape. Elements derived from several diverse sources in the investigation and evaluation of predevelopment conditions have been instrumental in developing a simulation of the natural lake. These materials are generally listed in in the references section at the end of the report.

Primary supporting information was derived from the mid- to late-1880s surveys of northern California and southern Oregon that had been completed by the USGS. These plane-table surveys were published as a series of standard 1:125 000 scale, 30 minute quadrangles and were used in other USGS publications (reports) as a base for posting field-surveyed information in describing and cataloguing the existing natural resources of the area. The most recent survey of interest (in this series) for Upper Klamath Lake was published in 1905 by the U.S. Reclamation Service as a 1:250 000 scale single-sheet compilation (USRS 6902) of several adjoining quadrangles in this 30 minute series. From a digital copy of the 1:250 000 scale compilation sheet, each of a series of 1:63 360 scale, 15 minute quadrangles were extracted and printed. These 15 minute extracted quadrangles covered the same area given by each of a series of *present-day* 15 minute planimetric quadrangles published in 1956-57 by the USGS at a scale of 1:62 500. The information contained on these 1905 extracts that related to the natural condition of Upper Klamath Lake was initially transferred, and then interpretively posted, onto scale-reduced copies of the same-area modern USGS 15 minute quadrangles, each of which was used as a base map for the compilation. These *present-day* sheets had initially been copied from originals at the published scale of 1:62 500, and then scale reduced to 1:63 360 thereby giving each sheet a conformable map scale useable for these postings. This map scale was generally chosen for all interpretive map products related to Upper Klamath Lake because the overlay of different map products, transfer of information from one map onto another, comparison of different map series, would all be at a common scale. Further, at this map scale, planimetry of delineated areas would yield one square mile for each square inch that was planimetered. Because each of the maps used for these compilations is planimetric, the planimetered areas would be considered representative. Additional information was derived from current 1:24 000 quadrangles covering the northern end of the lake. This additional information was posted on 1:63 360 scale reduced overlays derived from the 1:24 000 quadrangles.

Factors affecting the outfall response of the natural lake –

Implementation of a simulation for the natural Upper Klamath Lake required assessment of several factors related to predevelopment conditions that were directly affecting the hydraulic response of the lake to natural inflow. These factors are as follows:

1) Estimation of the predevelopment extent of the open-water surface area of the lake.
2) Estimation of the predevelopment extent and condition of natural marshlands attendant to the lake.
3) Estimation of the storage capacity of the natural lake.
4) Evaluation of the hydraulic response of the outfall from the lake due to storage-induced changes in water-surface elevation.

Items 1 and 2, above, were extracted by planimetry of the respective areas interpretively posted on the series of 15 minute *present-day* compilation sheets. Item 3, above, was estimated based on reasonable assumptions regarding the aerial extent of the water surface of the lake at specific given elevations of the water surface. The observed maximum high water surface of the lake (April, 1904) defined the estimated upper bound for the water-surface area and storage capacity of the lake. Item 4, above, was evaluated from historical information relating the monthly average elevation of the water surface of the lake, and the concurrent discharge from the lake that was recorded for monthly total flow of the Link River at Klamath Falls.

With the determined areas of the natural open-water surface and natural marshlands attendant to the lake, natural losses from this water body may be estimated. As these losses directly deplete the natural inflow to the lake, the net inflow will be stored, in part, and simultaneously released, in part, as the natural outfall from the lake. For the natural lake, the following were noted or conceptually developed from materials that were researched:

Lake natural wetland marsh area………..………………………... 53,306 acres
Attendant emergent marsh area……………………………………. 9,210 acres
Open water surface area……………………………….……….. 66,976 acres
Inundated area at maximum volumetric capacity……………….. 125,350 acres (estimated)
Maximum volumetric capacity above the sill elevation..………...768,000 ac-ft (estimated)
Lake surface elevation at maximum volumetric capacity..………. 4145.0 ft above USRS datum
Sustained average discharge at maximum volumetric capacity….…9,280 cfs or 600,000 ac-ft/mo
Outfall depth at maximum volumetric capacity………..………….. 7.2 ft (approx)
Outfall minimum discharge noted …………………………………. 0.0 cfs (July 18, 1918)
Outfall depth at minimum noted discharge ……………………..... 1.51 ft (approx)

Integration of the natural lake –

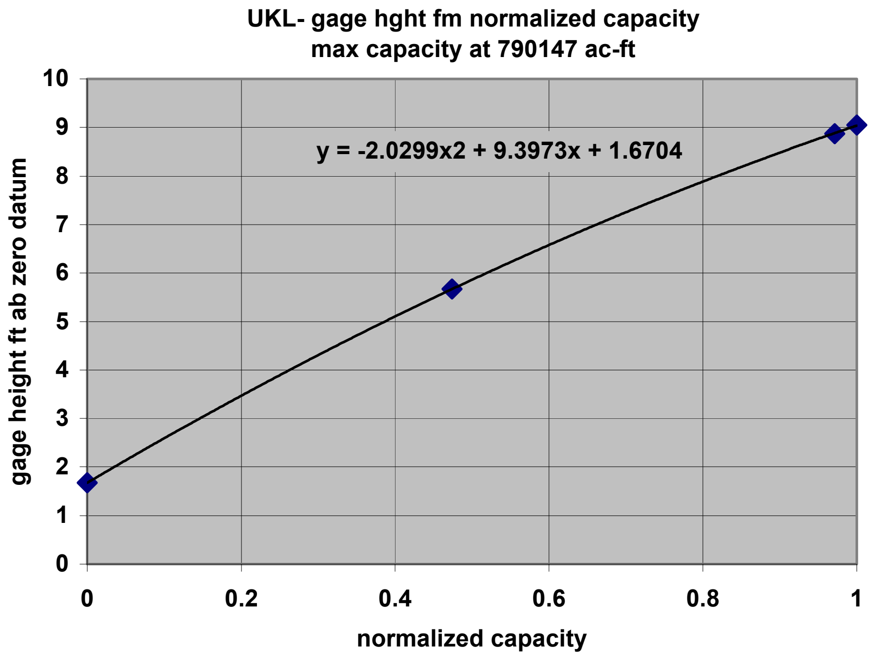
Once the natural inflow to Upper Klamath Lake has been determined, the interrelationship of the natural factors affecting the lake as an hydrologic system may be evaluated in a simulation. Because storage within the lake inundated natural wetland marshes associated with the lake, the lake wetland marshes comprise part of the storage capacity of the lake. Because the open water surface of the lake is bounded by a natural marshland perimeter, the open water surface area of the lake is conceptually fixed and does not vary. Natural inflow to the lake is stored, in part, and released from storage at the outlet of the lake in response to elevation of the water surface of the lake. The integration of these factors is somewhat simply interrelated and accounting for them is straightforward.

- *Area and capacity*

Capacity of the natural lake to store water is determined by the integration of changes in area with changes in depth. The change in area is easily determined as a function of depth where depth has been determined for the corresponding water-surface elevation of the lake. To begin, at the minimum elevation for discharge from the natural lake, 4137.8 ft, the open-water surface area of the lake may be assumed to have evacuated the area of wetland marsh attendant to the lake. As the depth of the lake increases above this elevation to the estimated natural shore of the lake at 4141.8 ft, the surface area of the storage prism also increases to the area indicated by the sum of the areas for the open-water surface and marsh. This is the area inundated by the lake at its stable water-surface elevation. The additional area inundated at the maximum observed water-surface elevation of the natural lake may then be integrated into the storage prism thereby allowing an estimate of the maximum natural capacity of the lake to store water. For the natural lake, then, the following were derived:

Elevation ft. above datum			Inundated area acres	Capacity acre-feet
USGS	*USRS/BOR*	*gage*		
4136.0	4137.8	1.67	66,976	0
4140.0	4141.8	5.67	120,282	374,516
4143.2	4145.0	8.87	125,349	767,526
4143.38	4145.18	9.05	126,000	790,147

For the natural lake, derived changes in inundated area and capacity may each be expressed as a function of the indicated gage height noted above the established zero datum for the gage. Although such information provides a conceptually useful view of the lake, a water-budget simulation of the lake will require gage height to be derived inversely as a function of storage. For Upper Klamath Lake, the elevation of the zero datum for the gage was established as 4136.13 ft above USRS datum at installation of the gage, and the required factors for gage height and storage must be related to this elevation. Useable information about gage height of the water surface was, therefore, derived from storage by calculating gage height as a



function of normalized capacity. Use of this curve would also provide information about the simulated elevation of the water surface of the natural lake. The resulting graph for this function is shown above.

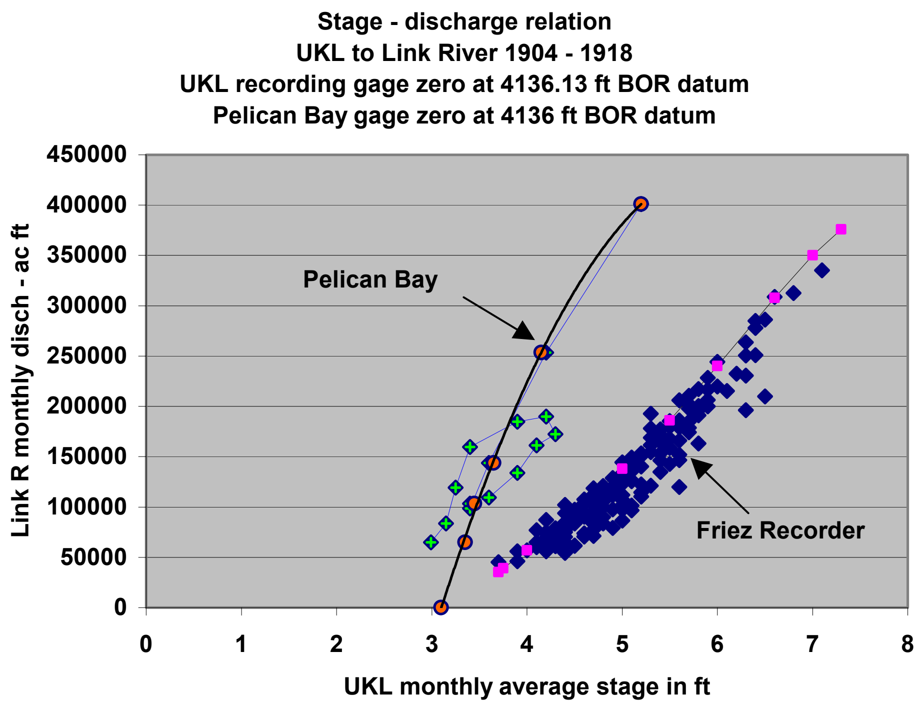
- *Elevation and discharge*

The discharge, or outfall, from the natural lake is dependent on the water-surface elevation of storage in the lake. Therefore, discharge from the natural lake may be directly related to gage height of the water surface. Given storage as a known factor in the water budget for the lake, the gage height, and hence discharge from the lake, may be calculated directly. To accomplish the discharge calculation, a discharge-rating curve must be derived for the natural lake based upon recorded monthly total discharge from the lake and the concurrently observed monthly average water-surface elevation. For the pre-dam period before the Link River crib dam was constructed, outfall from the lake was uncontrolled and dependent on the elevation of the water surface in the lake.

Evaluation of the rating curve was accomplished by noting the recorded monthly total discharge of the Link River, which was inclusive of diversions to the A canal, the Modoc power canal, and flow past the Link River gage. The monthly average water surface elevation of the lake was determined from records of the daily observed or daily recorded values at the gage above the outlet to the lake. Some of these data also included recorded water surface elevations at the Pelican Bay gage.

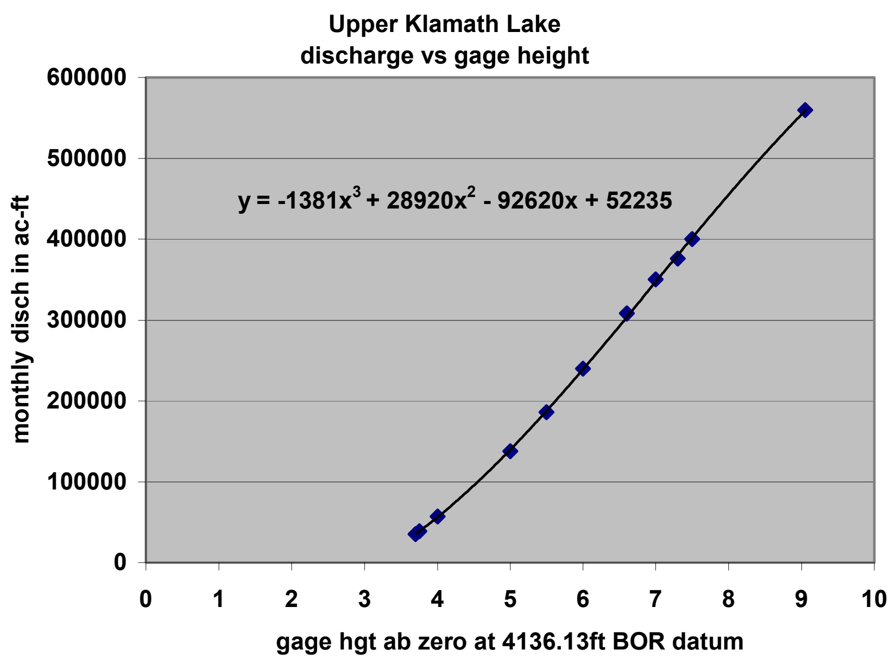
Problems with the Friez automatic recording gage near the outlet on Klamath Lake, however, had to be given special consideration in developing the rating curve. After initial installation of the Friez gage, the mechanism was not operating smoothly in response to changes in the water surface elevation of the lake and posed problems in the maintenance of accurate records. This difficulty, which caused a series of ongoing maintenance problems with the gage, was evidently related to the Friez automatic register and the integrated pulley assembly for the recorder. Further, up-valley winds were noted to decrease the outfall while maintaining the water-surface elevation of the lake. These two factors, problems with the recorder and winds on the lake, are commingled in the records for elevation of the water surface. Separation of difficulties evident with the Friez recorder was facilitated by the absence of daily values in the record. For these missing days, generally every few days or at least once weekly, a gage-height reading was noted for the water surface elevation of the lake. Computer processing of these data allowed very representative estimates of the average water-surface elevation for each month that was considered in the record. Deviations from a regularly smooth trace for discharge plotted against gage height were evident by the smearing of the scatter of plotted points away from a limiting envelope along the left side of the scatter plot. Therefore, in developing the rating curve for outfall from the lake, the limiting envelope at the left side of the data scatter (shown below) was used as the definition of the rating curve. The lowest value on this curve was derived from the daily total flow on July 18, 1918, when the record-lowest recorded daily water-surface elevation was noted for Upper Klamath Lake. Although up-valley winds occurring on this date caused flow from the lake to cease for a period of several hours, for the day a total discharge was noted.

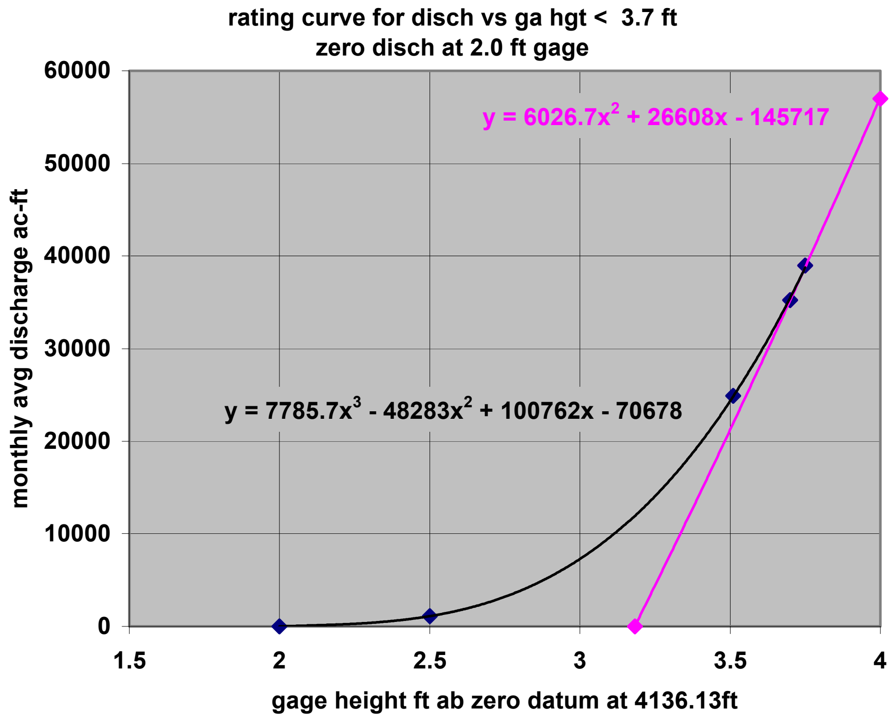
Closure of the curve to zero discharge was estimated by extension of the falling limb of the Pelican Bay monthly trace (left side of plot), and by extension of the curve along the limiting envelope of the outlet recording gage data. Both of these curves apparently achieve closure at about 3.183 feet gage. Because the outlet sill elevation would limit discharge to zero at 1.67 ft gage, the indication is that up-valley winds are holding back the lake and causing an adverse slope of the water surface against the wind. This condition is thereby limiting the outfall and giving an outfall depth of approximately 1.5 ft, more or less, for the water-surface elevation of the lake above the sill elevation of 4137.8 ft. This consequence would be consistent with the observed minimum discharge noted on July 18, 1918, and at other times preceding that date. Although not generally a common occurrence, the observation of zero discharge from the lake is, nonetheless, of significance to a simulation of the natural lake as indications regarding limiting outfall from the lake may be of importance to other considerations. Therefore, in conservatively deriving the rating curve for conditions approaching zero discharge, an alternative rating curve for simulated water-surface elevations less than 3.7 ft gage was primarily used for the comparison of results with those given by a rating curve derived from recorded water-surface elevations, alone. Use of the alternative rating curve, as a conservative measure, is intended to preclude underestimation of the outfall, and maintain determination of representative results. The data plot and curves derived are illustrated below.



Estimated data establishing the curve along the limiting envelope were used directly for the generalized rating curve. Monthly average readings for gage height of the water surface at the outlet-recording gage are shown at the right of the graph, and from the gage at Pelican Bay, at the left. Of note is the discordance of readings for Pelican Bay with those of the outlet gage. Pelican Bay data provided no substantial information for the rating curve. Of note regarding the recording gage defined rating curve, is the flexure tending slightly downward above 6.0 ft gage. This flexure indicates that at the higher discharges indicated above 6.0 ft gage, the outlet channel is increasingly regulating the uncontrolled outfall from the lake.

For use in the simulation, the rating curve was extended to 9.05 ft gage to capture conditions evident during the maximum-recorded water surface of the lake, which occurred in mid-April, 1904. Also, extension of the curve for an alternate rating curve below 3.7 ft gage, was forced to closure for zero flow at 2.0 ft gage, a seemingly representative value for zero discharge. Elements of each curve are shown below.




rating curve for disch vs ga hgt < 3.7 ft
zero disch at 2.0 ft gage
60000
50000
40000
30000
20000
10000
0
1.5
2
2.5
3
3.5
4
y = 6026.7x2 + 26608x - 145717
y = 7785.7x3 - 48283x2 + 100762x - 70678
monthly avg discharge ac-ft
gage height ft ab zero datum at 4136.13ft

<u>Predevelopment aspects of Lower Klamath Lake</u> –

Lower Klamath Lake, as documented by the U.S. Reclamation Service in 1905, was already showing changes due to development. However, much of the predevelopment aspect of the lake, and marshlands, was still in place. Some environmental and hydrologic aspects of the lake may be surmised from somewhat scant yet apparently well documented field evidence about some of the observed conditions at the lake. Documents reviewed about Lower Klamath Lake are listed in the reference section at the end of the report.

The predevelopment lake seemed vast given the sense of the associated marshland and open water comprising the lake. Generally, the natural Lower Klamath Lake was a very shallow water body that averaged less than about 4 or 5 feet in depth. The broad wetland marsh surrounding the central, open-water area of the lake, was growing in very shallow water that had little depth near the lakeshore. Two to three 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 not larger than just a few acres. Although contiguous bulrush areas did not invade deeper water, the marsh apparently bridged some narrower sections of open water thereby giving this marshland a reach from the southeastern to the northeastern shore of the lake. The greatest expanse of open water was in the deeper, southern portion of the lake where evaporation made the lake moderately alkaline. This increased alkalinity was probably a factor limiting the growth of bulrush within that part of the lake. Alkalinity was apparently so high within White Lake, at the eastern limit of the northeastern shore, that no bulrush could invade. Further, nearing the end of the summer, warm water may have been resident especially within the more alkaline, southern part of the lake that held the deepest water. As evaporation lowered the water surface of Lower Klamath Lake during the summer, the presence of this warm water was enhanced by the late-summer influx of warm water issuing from Upper Klamath Lake. During the most typical years, the stable water-surface elevation for the lake was probably about 4084 to 4085 feet, more or less.

Evidence suggests that the flood of 1890 was of such magnitude that the water-surface elevation of Lower Klamath Lake may have exceeded 4088 feet for a considerable time. Under these conditions, much of the lake would have appeared as open water. Wetlands attendant to the lake, especially within the central portion of the water body, would have been submerged and would not have thrived. 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. Hence, there may have been times when the open-water area of the lake was much more expansive and dominant than seen typically. Further, flow through the Lost River Slough would have been considerable, perhaps exceeding 800 to 1000 cfs during such floods.

Evidence also suggests that during drought, the wetland marsh succumbed to the dry conditions and deteriorated. 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. Within the hot, dry summer months of such times, vast expanses of the wetland were fetid. Open-water areas were somewhat shallower, and during such dry conditions, would have been warmer and more brackish. The water-surface elevation of the lake during such dry years may have been somewhat less than 4083 feet 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 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 ground-water underflow. Hence, Miller Lake was a part of Lower Klamath Lake. Due to extreme evaporation, the water within Miller Lake was highly alkaline and, consequently, the water-surface elevation in Miller Lake would always have been somewhat lower than in Lower Klamath Lake. The difference in elevation between the water surface of Lower Klamath Lake and that of Miller Lake would have been the driving force for the ground-water underflow.

In 1905, the reclamation of Lower Klamath Lake began for recovery of the land to agricultural uses. By 1917, with closure of the Klamath Strait, the ending phase was initiated in draining the vast area of open water and marshland of Lower Klamath Lake. Within a decade, the natural character of Lower Klamath

Lake was gone. Over the intervening time to the mid-1950s, the dry lakebed of Lower Klamath Lake was extensively reclaimed for irrigated agriculture and this reclaimed area is part of the Klamath Project operated by the U.S. Bureau of Reclamation. However, as the lake had at one time been one of the most diverse ecosytems in North America, being along the Pacific flyway, a designated portion of the drained lakebed was set aside and allowed again to be filled, which is now the Lower Klamath National Wildlife Refuge.

<u>Evaluation of the natural Lower Klamath Lake</u> –

The vast expanse of Lower Klamath Lake and its marshlands presented an obstacle to seeing or understanding the nature of the lake. However, until settlement, which accelerated after the Civil War, the region still remained largely unexplored. To evaluate the natural condition of Lower Klamath Lake, materials documenting the frontier condition of the landscape were reviewed. 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 the USGS. Earliest of these regards the report in which notes of Lt. R. S. Williamson are compiled describing the condition of the frontier that he saw in 1855. Although information by Williamson is generally of incidental interest, certain elements in the description of the landscape provide a view that has assisted in the interpretive aspects giving definition to the natural lake, and in visualizing the landscape. Much of the information, however, was derived from several diverse sources that are listed in the reference section at the end of the report. Most are anecdotal yet have been instrumental in developing a conceptual understanding of the lake.

Primary supporting information was derived from a planimetric survey of the lake completed and published by the U.S. Reclamation Service in 1905. This very detailed survey, which was completed using plane-table methods, was published at a scale of 1:48 000. Because the survey was of the lake in its natural condition, information related to marshlands and open water could be easily assessed. Important information regarding the mapped aspect of the natural lake was transferred to a mylar overlay at a scale of 1:73 184. Each significant area was defined and planimetered, including overflow areas that would have held water in storage during high-water events. From the compiled information from the 1905 survey, a detailed concept for the lake was developed based on the planimetered areas of marshland, open water, and overflow areas that were evident. From this information, a composite curve was developed for depth of the lake versus storage.

An interconnected lake –

For Lower Klamath Lake, natural inflow to the lake is comprised solely of the natural outfall from Upper Klamath Lake and measured ground-water inflow (Quinton, 1908) from springs. The natural condition of Lower Klamath Lake, however, was a system of two lakes in addition to a complex of marshes and open water. At the outlet of Upper Klamath Lake is the elongated Lake Ewauna, which forms the head of the Klamath River. The winding channel of the Klamath River issues from Lake Ewauna, and follows a generally sinuous southwesterly course for several miles along the northwestern margin of Lower Klamath Lake before turning abruptly northwest near the lake outlet in the vicinity of Keno. 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 an elevation of about 4084 ft. 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 and 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, as noted above, also carried water out of the lake system when the water surface elevation exceeded 4085 feet.

Aspects affecting the natural hydrologic response of Lower Klamath Lake were controlled by 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, and storage of water within the interconnected lake prism. Inflow from the Link River supported losses from the marshlands and evaporation from the open water surface. At the onset of the seasonal late-spring maximum in streamflow from snowmelt, and consequent maximum in outfall 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 outfall 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 elevation above 4085 ft, 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 the lake in response to this seasonal inflow was less than about 3 feet, more or less.

Factors affecting the outfall response of the natural lake –

Implementation of a simulation for the natural Lower Klamath Lake required assessment of several factors related to predevelopment conditions that were directly affecting the hydraulic response of the lake to natural inflow. These factors are as follows:

5) Predevelopment extent of the open-water surface area of the lake.
6) Predevelopment extent and condition of natural marshlands attendant to the lake.
7) Estimation of the storage capacity of the natural lake.
8) Evaluation of the hydraulic response of the outfall from the lake due to storage-induced changes in water- surface elevation.

Items 1 and 2, above, were extracted by planimetry of the respective areas shown on the 1905 survey. Item 3, above, was estimated based on reasonable assumptions regarding the aerial extent of the water surface of the lake at specific given elevations of the water surface. This estimate of storage capacity was based on the integrated storage within Lower Klamath Lake, overflow storage within the Lost River Slough, and storage possible in Lake Ewauna. The estimated upper bound for the water-surface area and storage capacity of the lake was determined as the elevation contour approximating 4088 ft above the USRS datum. Item 4, above, was evaluated from historical information relating the monthly average elevation of the water surface of the lake, and the concurrent discharge from the lake that was recorded for monthly total flow of the Klamath River at Keno.

With the determined areas of the natural open-water surface and natural marshlands attendant to the lake, natural losses from this water body may be estimated. As these losses directly deplete the natural inflow to the lake, the net inflow will be stored, in part, and simultaneously released, in part, as the natural outfall from the lake. For the natural lake, the following were noted or conceptually developed from the 1905 survey:

Natural marshland………………………………………………………. 55,842 acres
Open water surface……………………………………………………… 34,994 acres
Capacity……………………………………………………………………. 332,000 ac-ft (approx)
Elevation change across capacity……………………………………… 3.85 ft
Water surface elevation at maximum capacity………………………... 4088 ft (USRS datum)

Integration of the natural lake –

Once the natural inflow to Lower Klamath Lake has been determined, the interrelationship of the natural factors affecting the lake as an hydrologic system may be evaluated in a simulation. Because storage within the lake inundated natural wetland marshes associated with the lake, the lake wetland marshes comprise part of the storage capacity of the lake. Because the open water surface of the lake is bounded by a natural marshland perimeter, the greatest part of the open water surface area of the lake is conceptually fixed and does not vary. The open-water area formed during higher water overflow and inundation of mud-flat and significant shore areas, however, varies with changes in elevation. Natural inflow to the lake is stored, in part, and released from storage at the outlet of the lake in response to elevation of the water surface of the lake. The integration of these factors is somewhat simply interrelated and accounting for them is straightforward.

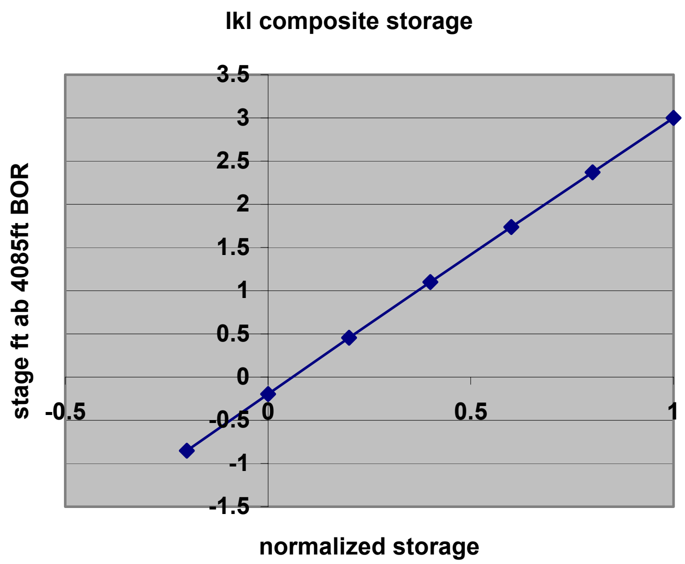
- *Area and capacity*

Capacity of the natural lake to store water is determined by the integration of changes in area with changes in depth. The change in area was conceptually determined as a function of depth where depth is directly related to the corresponding water-surface elevation of the lake. To begin, the datum for an outfall gage was defined indicating the reference elevation for an assumed static water surface elevation of the lake. Storage and discharge were referenced to this datum. The zero reference for this *gage* datum was at 4085 ft above the USRS datum. The minimum elevation for discharge from the natural lake was taken as 4083.1 ft above the USRS datum, the reef elevation at Keno. As the depth of the lake increases above 4085 ft to the estimated maximum water-surface elevation of the lake, the surface area of the storage prism also increases. This additional depth and inundated area may then be integrated to yield the volume of the storage prism thereby allowing an estimate of the maximum natural capacity of the lake to store water. The curve defining storage capacity was also extended for water-surface elevations below the zero gage elevation. This allowed the determination of storage for anticipated conditions simulating water-surface elevations below 4085 ft. For the natural lake, the following were conceptually derived:

LKL composite storage:

Lower Klamath Lake		Lost River Slough		Lake Ewauna		Composite LKL			
datum -	4084.8	datum -	4085	datum -	4085.1	datum -	4085		
lkl elevn	strg ac-ft	lkl elevn	strg ac-ft	lkl elevn	strg ac-ft	lkl elevn	strg ac-ft	stage	nrml strg
4084.8	0								
4085	16643.63	4085	0	4085.1	0	4085	16643.63	0	0.060169
4085.2	33301.72	4085.2	98.0778	4085.2	142.958	4085.2	33542.76	0.2	0.121262
4085.4	49974.28	4085.4	221.5432	4085.4	431.0823	4085.4	50626.9	0.4	0.183023
4085.6	66661.3	4085.6	370.3962	4085.6	722.1509	4085.6	67753.84	0.6	0.244939
4085.8	83362.78	4085.8	544.6368	4085.8	1016.164	4085.8	84923.58	0.8	0.30701
4086	100078.7	4086	744.265	4086	1313.121	4086	102136.1	1	0.369236
4086.2	116809.1	4086.2	969.2808	4086.2	1613.022	4086.2	119391.4	1.2	0.431616
4086.4	133554	4086.4	1219.684	4086.4	1915.868	4086.4	136689.5	1.4	0.494151
4086.6	150313.3	4086.6	1495.475	4086.6	2221.658	4086.6	154030.4	1.6	0.55684
4086.8	167087.1	4086.8	1796.654	4086.8	2530.392	4086.8	171414.1	1.8	0.619685
4087	183875.4	4087	2123.22	4087	2842.071	4087	188840.6	2	0.682684
4087.2	200678.1	4087.2	2475.174	4087.2	3156.693	4087.2	206309.9	2.2	0.745838
4087.4	217495.2	4087.4	2852.515	4087.4	3474.261	4087.4	223822	2.4	0.809146
4087.6	234326.9	4087.6	3255.244	4087.6	3794.772	4087.6	241376.9	2.6	0.872609
4087.8	251173	4087.8	3683.361	4087.8	4118.228	4087.8	258974.6	2.8	0.936227
4088	268033.5	4088	4136.865	4088	4444.627	4088	276615	3	1

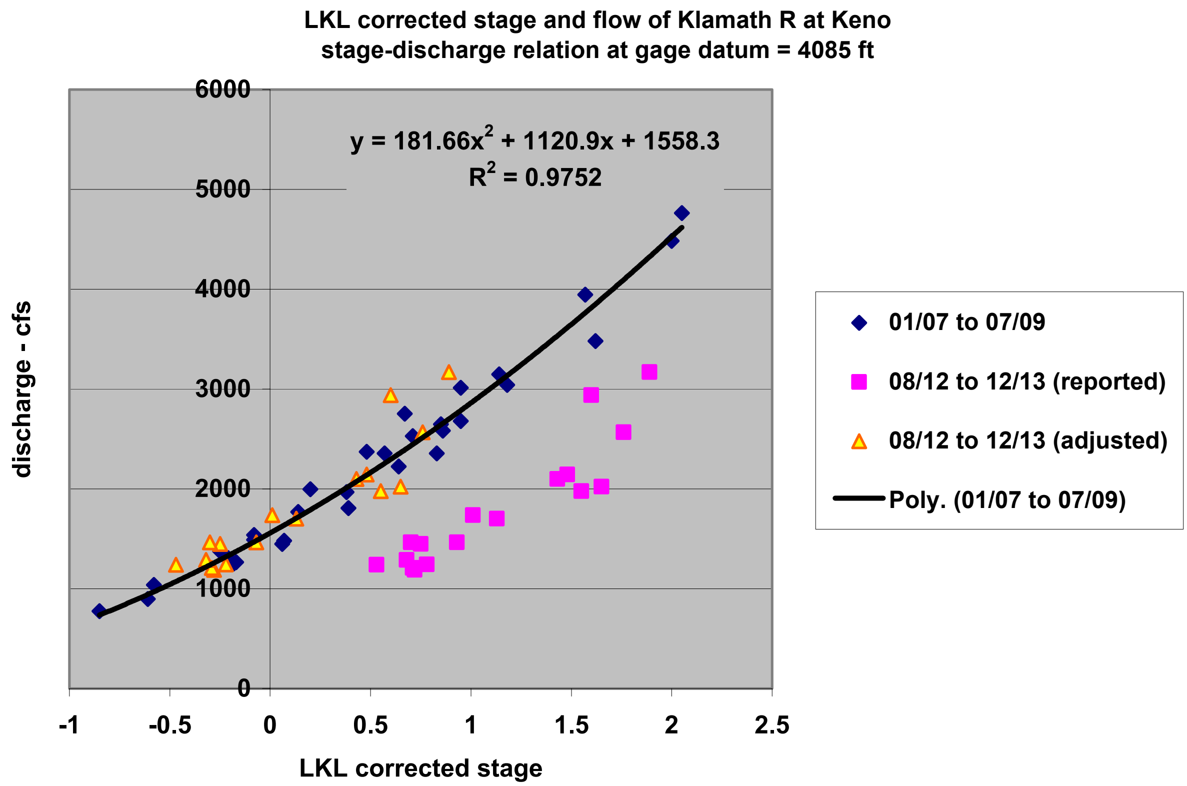
For the natural lake, derived changes in inundated area and capacity may each be expressed as a function of the indicated gage height, or lake stage, noted above the established zero datum for the gage. Although such information provides a conceptually useful view of the lake, a water-budget simulation of the lake required gage height to be derived inversely as a function of storage. For Lower Klamath Lake, published records of the water-surface elevation at the USRS maintained recording and staff gage may be referenced to the datum at 4085 ft. Required factors for gage height and storage must be related to this elevation. Useable information about gage height of the water surface was, therefore, derived from storage by calculating gage height, or lake stage, as a function of normalized capacity. Use of this curve would also provide information about the simulated elevation of the water surface of the natural lake. The resulting graph for this function is shown below.



- *Elevation and discharge: The Klamath River at Keno*

The discharge, or outfall, from the natural Lower Klamath Lake was conceptually related to the water-surface elevation of storage in the lake. Given storage as a known factor in the water budget for the lake, the gage height, and hence discharge from the lake, may be calculated directly. To accomplish the discharge calculation, a discharge-rating curve must be derived for the natural lake based upon recorded monthly total discharge from the lake and the concurrently observed monthly average water-surface elevation. Evaluation of the rating curve was accomplished by noting the recorded monthly total discharge of the Klamath River at Keno, and the concurrent monthly average water surface elevation determined from published records of the daily observed or daily recorded water surface gage height for the lake. Computer processing of the recorded daily elevation data allowed very representative estimates of the average water-surface elevation for each month that was considered in the record. In addition, discharge through the Lost River Slough must be considered and related to water-surface elevation of the lake.

For the Klamath River at Keno, the relationship for concurrent elevation of the water surface and discharge recorded at the gage is shown below. Published data for the gage readings from August, 1912, to December, 1913, were reported in reference to an erroneous datum for the gage. Correction of the reference datum allowed adjustment of these records to come into agreement with previous readings. Reported lake elevations from January, 1907, to July, 1909, were used to establish the rating curve for discharge used in the simulation, as shown in the plot, below. Closure of this rating curve for zero discharge is at 4082.9 ft above USRS datum. The actual limiting elevation of the reef at Keno is approximately 4083.1 ft.



- *Elevation and discharge: The Lost River Slough*

A natural overflow channel at the outlet of Lake Ewauna, the Lost River Slough, carried water out of the Klamath River drainage during higher-water storage events occurring in Lower Klamath Lake. During such events, Lake Ewauna was inundated and a continuous part of Lower Klamath Lake. Storage in Lower Klamath Lake resulting in a water-surface elevation greater than 4085 ft caused overflow into the Lost River Slough. This water would then flow into the closed basin of the Lost River, and into Tule Lake. To evaluate the nature and volume of flow through the Lost River Slough, an evaluation of the hydraulic performance of the stream channel would be required. This evaluation was necessary to derive a rating curve for discharge through the slough that could be used in the simulation of Lower Klamath Lake, just as the rating curve developed for flow from the lake at Keno. The flow characteristics of the Lost River Slough as the slough existed in the early part of the 20th century were therefore studied using engineering and hydraulic computational methods. A rating curve for the 1905 Lost River Slough was developed using normal and critical flow depth calculations and standard backwater profiles based on the U.S. Army Corps of Engineers HEC-RAS River Analysis System Version 3.0.1 Mar 2001. The condition of the slough as evaluated would be the same that existing under natural conditions prior to construction of the dike closing the slough in 1890.

The Lost River Slough is a section of river channel between the Klamath River and the Lost River. The slough would operate as a flowing channel only when there was sufficient flow and volume in the Klamath River and Lower Klamath Lake such that a backwater effect caused high elevation in the Klamath River at the entrance to the Lost River Slough and water began to flow by gravity into the slough. The Lost River Slough in the early part of the century was a meandering channel in a relatively wide, flat valley with potential islands that could develop and become submerged under high flow conditions. The slope of the channel bed is unknown so only the average slope of the river as a unit could be determined. The entire valley could convey flow since the elevation difference from side to side is potentially less than 2 feet. The entire left side (looking downstream) of the valley was potentially either a non-contributing flow area or a separate flow channel. The main flow channel was assumed to be comprised of rounded cobbles, gravels, and sand free of vegetation. The land outside of the main channel was estimated to be of alternately dry land or wet marshy land comprising of some cobbles and gravels with grasses and other low bushy vegetation.

The slope of the river was determined from topographic contours mapped by the USRS in 1905, as mentioned below. The limits of the Lost River Slough were delineated as that section between the Klamath River and the Lost River, or along the channel approximately 7 miles in length. The contours in that reach ranged from elevation 4085 to elevation 4082.5 so there is only about 2.5 feet fall over that length. The active channel was delineated but with only the 2.5 foot contours shown, the channel bottom elevation could not be determined. The average slope was determined using the known contours and the river distance between them. To estimate the *thalweg* (bed slope) an average slope from the highest contour to the lowest contour was used. This resulted in an average slope of 6.3928×10^{-5}, which was used for the entire reach of the river. The river distance was measured off the Department of the Interior, U.S. Reclamation Service, Topographic and Irrigation Map, Upper and Lower Klamath Projects, California – Oregon, 1905. The U.S. Geological Survey, Reclamation Service, Klamath Project, California – Oregon, General Progress Map, April 1905 was also used. The minimum stream channel elevation for computation purposes was calculated using the station and the average bed slope, located in the center of the channel with average slope up to the water line.

Six cross sections were developed along the Lost River Slough (designated Station 394+99.6, Station 332+86.4, Station 286+52.1, Station 277+06.2, Station 227+66.3 and Station 19+52.45). The first station is approximately 100 feet downstream from the elevation 4085 contour and the last station is upstream from the elevation 4082.5 contour. The locations for these cross sections were determined from the channel topography as potential flow control locations based on the width of the active channel at that location. Cross sections for the entire valley width were developed to include the entire range of flow depths with both the left and right edge extended to include all potential flow depths and with maximum elevations high enough to contain the expected flows. The cross sections were developed perpendicular to the expected flow channels not necessarily as a straight line across the valley. The active flow channel was developed from the plan for the low flow conditions with the over-banks and ineffective flow areas additional areas for calculations.

The HEC-RAS file was developed based on the 6 main cross sections, a Manning's n roughness coefficient of 0.024 for the main flow channel, and a Manning's n roughness coefficient of 0.036 for the over-bank channel sections. The Manning's n was determined from photographs using USGS Water Supply Paper 1849, Roughness Characteristics of Natural Channels, 1967. The main channel in the Lost River Slough was conceptualized as rounded cobbles and gravels free of vegetation. The over-bank areas were described as cobbles, gravels, weed and grass cover. Cobbles and gravel for the slough were most likely sourced from constricted channel areas such as that adjacent to Miller Hill. Some of the larger material in the channel could have been derived from terraces and prograded stream alluvium carried into the slough from the Klamath River or from Link River.

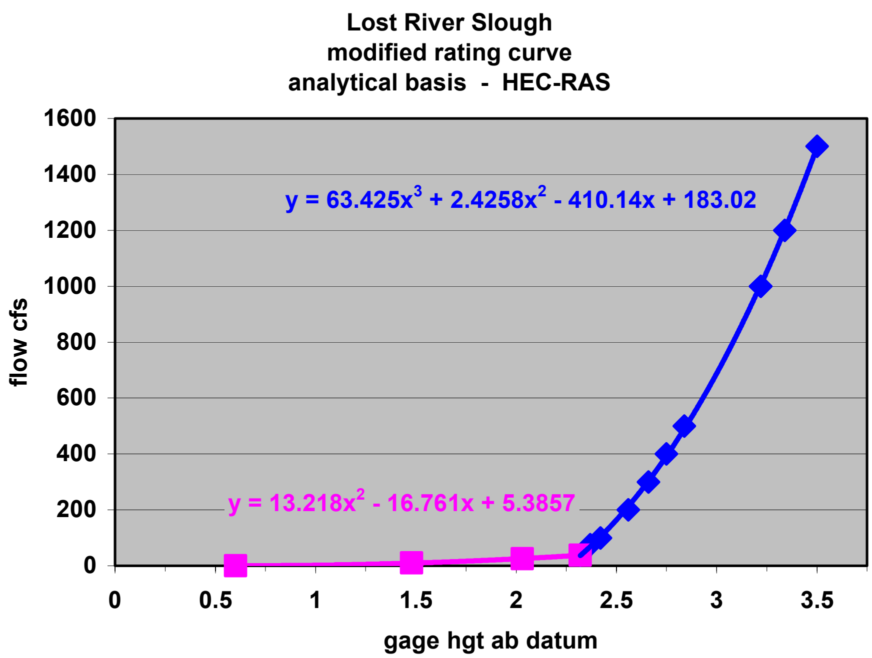
Fourteen flow discharges; 10-, 25-, 50-, 75-, 100-, 200-, 300-, 400-, 500-, 1000-, 1200-, 1500-, 2000-, and 3000-ft^3/s; were used for calculations purposes to determine the rating curve for each developed section. These flows were based on the need to define the boundaries of the lower flow ranges as well as an upper flow range. The HEC-RAS program was run for individual control sections, for short reaches with multiple sections, and for the entire reach. A rating curve was developed for critical and normal depth at each section for various flows. Additionally, a rating curve was developed for section 1 derived from the backwater curve based on a subcritical flow regime with either critical or normal depth at the downstream control point back upstream. This rating curve for section 1, with 6 control sections, was ultimately used to develop the *rating curve* for the Lost River Slough.

The developed Lost River Slough rating curve is a fixed rating curve which was selected to simplify the computations. There is a hysteresis effect which occurs on the Lost River slough and affects the rating curve. The hysteresis effect is a very real hydraulic anomaly indicating the rating curve will have a lower stage for a given discharge when flow first occurs at the upstream end of the reach, but the stage rises for the same discharge as the valley becomes filled with more water. The selected rating curve begins at elevation 4085 based on that contour as the control elevation in the upper reach of the basin for the Lost River Slough. The flow control section for the Lost River Slough is initially located at station 394+99.61. As flow increases, the valley begins to accumulate storage and the control section moves downstream (hysteresis effect). However, due to the low slope of the river and valley, the large amount of ineffective flow area to the left (north) of the active channel, and the large amount of storage in the ineffective flow areas, the water surface elevations at Section 394+99.61 are impacted by backwater effects. The water surface elevation at Station 394+99.61 is that determined through a step-backwater method to account for the hydraulic losses in the system and control at the downstream sections. During the decreasing leg of the rating curve, the same elevation will have a lower discharge rating because the flow at that time is controlled by the downstream sections and the backwater effects caused by storage of water within the channel.

The rating curve used in the simulation was based the evaluation of all of the rating curves for the sections as applied with the resulting backwater effects to the entrance to the Lost River Slough at section 1, Station 394+99.6. The selected rating curve was based on control at section 4, Station 277+06.2 and not at the lowest section, Station 19+52.45, with no hysteresis effects. This conclusion was based on the use of monthly time steps in the overall simulation with monthly averaged elevations and accompanying flows. The period of one month may be sufficient to fill the volume of contributing area in the Lost River Slough and cause the hysteresis effect. The storage volume accumulated in the Lost River Slough will create backwater and the lower discharges versus stage in the hysteresis will take effect. The use of Station 19+52.45 rating curve would create a higher water surface with lower flows into or out of the Lost River Slough.

The maximum flow though the Lost River Slough peaked at 114 ft^3/s; which correlates to an elevation 4087.4 and a stage of about 2.4 feet in the rating curve at Station 394+99.6 control section based on control at Station 277+06.2. If a control section further upstream had been used, this would over estimate the flow into the Lost River Slough on a monthly basis, but use of that control would be appropriate for shorter time periods. If a lower control section had been used that would have resulted in even lower flows into the Lost River Slough and would have been appropriate only if the duration and amounts of flow lasted many months. The use of this middle section is considered reasonable given the hysteresis effects and the time durations. The duration of flow into the Lost River Slough ranged from 1 month to a maximum of 6 months with 16 out of 40 flow periods lasting 1 month, 10 periods lasted 2 months and 9 periods lasted 3 months. The last 5 periods were 3 periods of 4 months, and 1 period each of 5- and 6-months.

The rating curve for the slough as used in the simulation, is shown below. This rating curve was slightly modified to accommodate smoothing the transition from the lower flow regime below elevations of about 4087.5 ft, to those higher, which is seen as a discontinuity in the curve at about 2.3 ft gage. The datum for the zero of this gage, as mentioned previously, is 4085 ft above USRS datum.


Lost River Slough
modified rating curve
analytical basis - HEC-RAS
y = 63.425x3 + 2.4258x2 - 410.14x + 183.02
y = 13.218x2 - 16.761x + 5.3857
flow cfs
gage hgt ab datum
0
200
400
600
800
1000
1200
1400
1600
0
0.5
1
1.5
2
2.5
3
3.5

<u>Simulation methodology for Upper and Lower Klamath Lakes</u> –

The basis for simulation of Upper and Lower Klamath Lakes is the *hydrologic equation* which is, simply,

inflow = outflow + change in storage .

With the given preceding information regarding lake-attendant marshlands, open-water surface area, and the relationship of storage and outfall to lake stage or gage-height elevation of the water surface, implementation of the hydrologic equation is very straightforward. A relationship for gage-height of the water surface versus storage in the lake has been developed and is readily at hand. Similarly, a discharge-rating curve has also been developed for these same data where the relationship for monthly total outfall from the lake may be computed from the determined monthly average water surface elevation. For the lake, the basic conceptual process accounting for the monthly water budget is as follows:

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

storage = residual storage + net inflow

water surface gage elevation = gage elevation (storage)

outfall = discharge rating curve (water surface gage elevation)

residual storage = storage - outfall

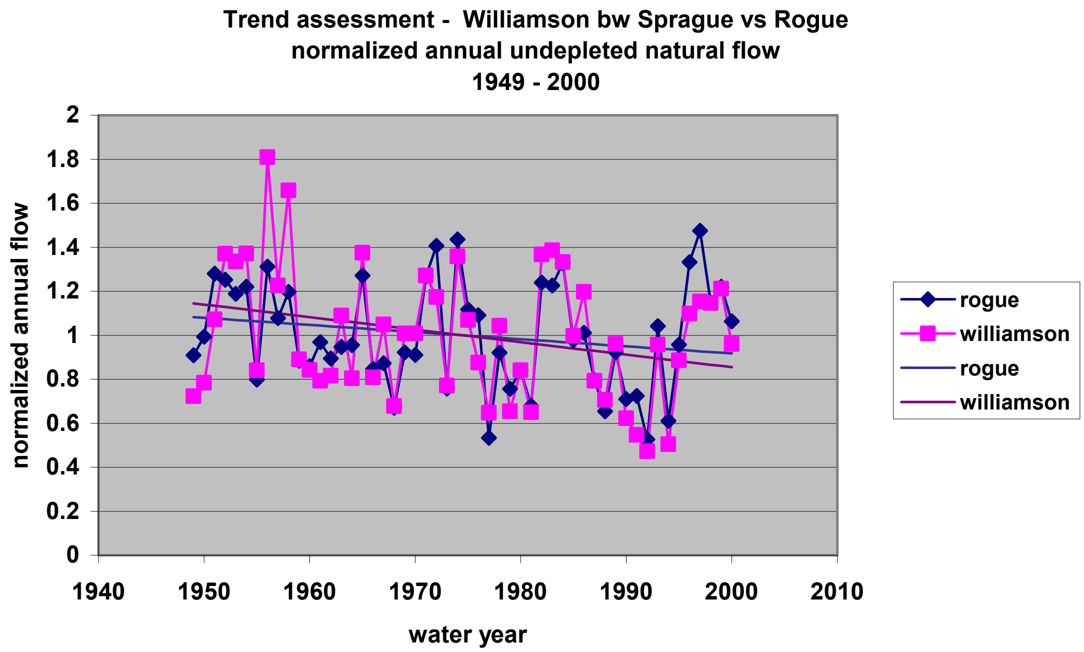
The sequence indicated in the water budget accounting, above, is simply repeated on a month-to-month basis in *acre-feet per* month for the selected 52 yr period of record. The resulting records of interest are for natural outfall from Upper Klamath Lake to the Link River, natural outfall from Lower Klamath Lake to the Klamath River at Keno, and monthly average elevation of the water surface of each of the lakes.

***<u>Water balance of the natural Upper Klamath Lake</u>* –**

The balance of the natural inflow to Upper Klamath Lake and attendant losses from the associated marshlands and the open water surface of the lake results in outfall from the lake at Link River. Inflow to the lake is therefore supporting these losses. The magnitude of each factor in the water balance may be described by examination of its respective time series.

- *Williamson Rive–*

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. Together, the combined inflow of these streams was determined as an annual average of about 910,000 ac-ft for the 52 yr period of record being considered Examination of the normalized annual time series for this inflow, in comparison with the Rogue, shows the indication that both streams have a declining trend and that the reconstructed natural flow of the Williamson appears to be consistent with that observed in another natural flow system within the regional climatic regime. A plot of the trend assessment for the annual time series, as referenced earlier, is shown below.



- *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 the Wood River and Crooked Creek, total natural inflow from these streams was found to average just more than 370,000 ac-ft per year for the 52 yr period of record. Streams on the west side of the valley were determined to have a natural inflow averaging nearly 118,000 ac-ft for the 52 yr period of record. The combined natural inflow from the Wood River Valley averages approximately 488,500 ac-ft per year for the 52 yr period of record.

- *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 comprise losses that are supported by the natural inflow to the lake. Marshlands are comprised of lake wetland marsh that is continually inundated by storage in the natural lake, and lake emergent marsh that is subirrigated from ground water that is associated with the natural lake. For the slightly more than 62,500 acres of marshland associated with the natural Upper Klamath Lake, these attendant losses averaged about 85,200 ac-ft per year for the 52 yr period of record. For the same period, net evaporation from the nearly 67,000 acres of open water surface of the lake averaged about 158,300 ac-ft per year.

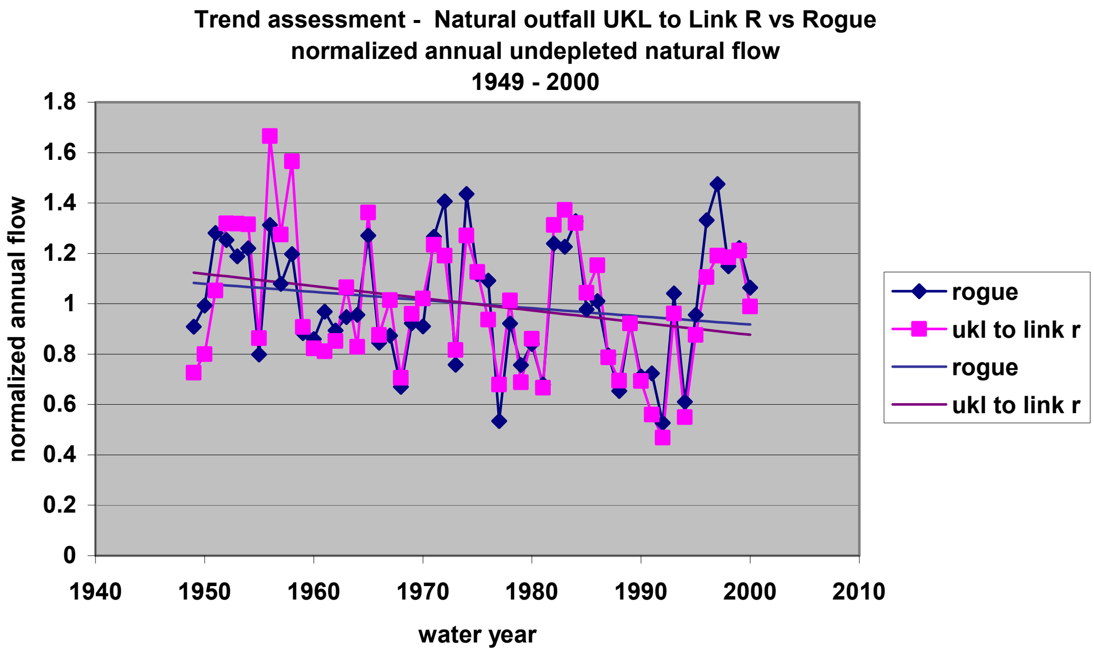
- *Resulting water balance for Upper Klamath Lake*

The resulting natural outfall of Upper Klamath Lake is the consequence of total inflow and net loss. For natural lake conditions, the water balance rounded to the nearest thousand acre-feet, below, is the result and includes an estimated 6000 ac-ft per year of unmeasured ground-water accrual to the lake.

Average annual natural inflow……………………….. 1,405,000 ac-ft
Average annual natural net loss ……………………... 244,000 ac-ft

Resulting average annual natural outfall..……………. 1,161,000 ac-ft

This result is comparable with the simulated average annual natural outfall of Upper Klamath Lake which includes the annualized residual storage carried in the final time step of the simulation. The comparable trend analysis for this outfall is shown below.

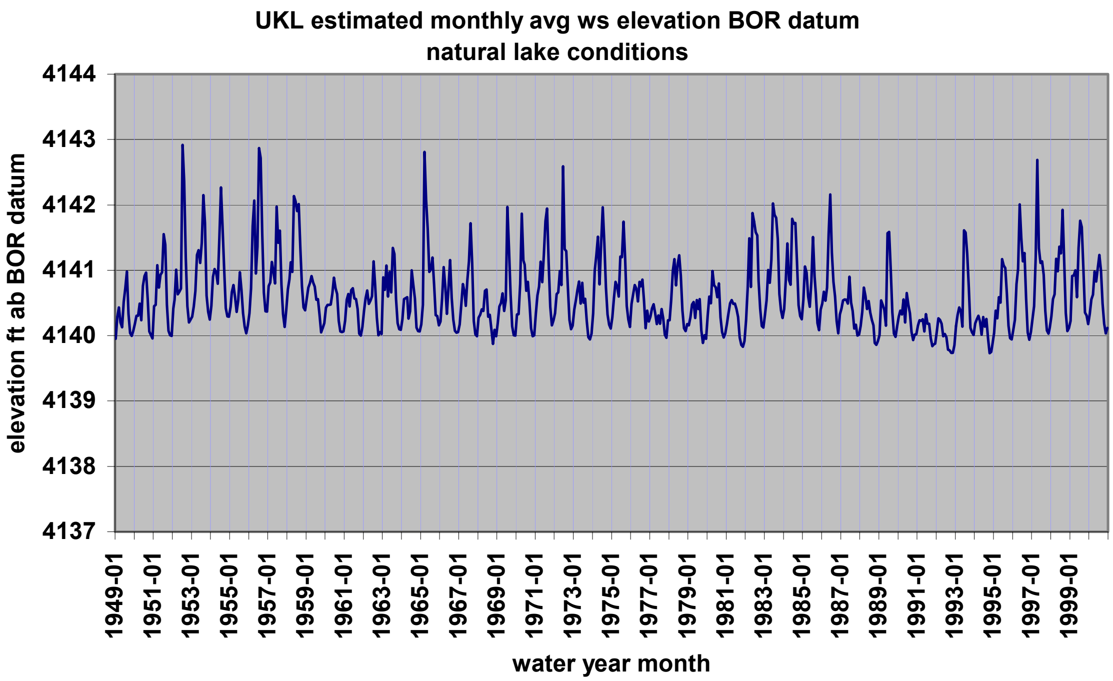


Discussion –

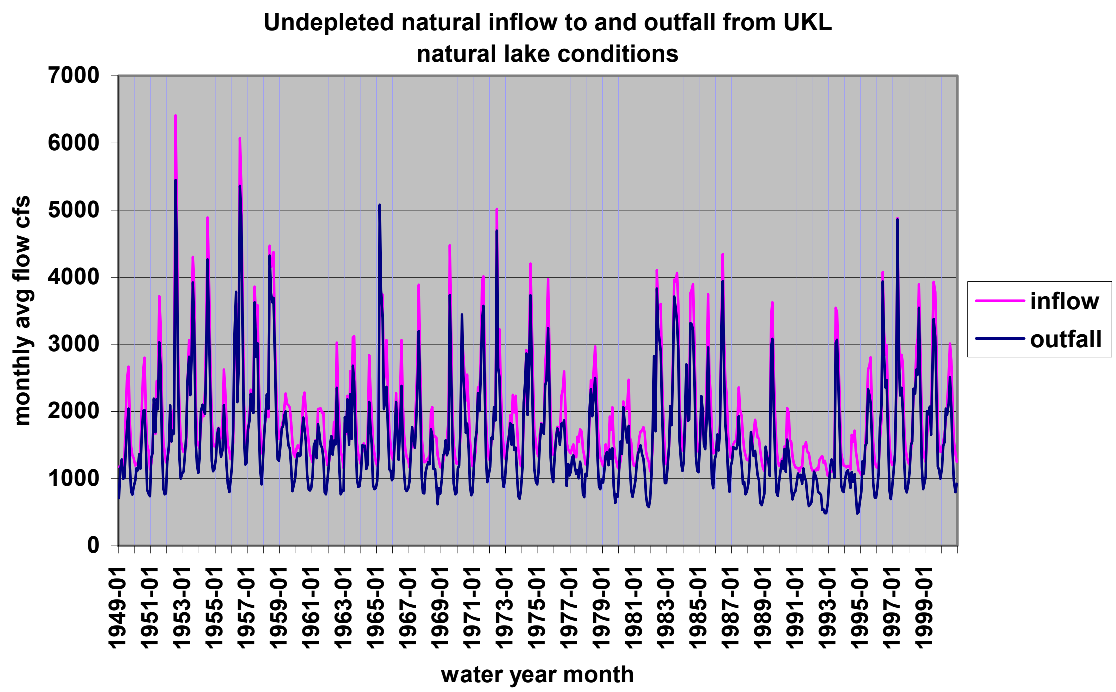
The process developed for the water budget for evaluating the undepleted natural outfall of Upper Klamath Lake appears to adequately account for factors in the watershed that have affected inflow to the lake, and for losses due to natural condition of the lake. Watershed conditions were examined and changes in streamflow due to irrigation of croplands was evaluated. Simulated outfall from Upper Klamath Lake was based on a conceptually straightforward explanation of the dynamic response of the lake to net inflow and storage within the lake as a natural water body. Records used in developing this analysis, which is an empirical assessment, were derived from both stream gaging flow histories, and from climatological records for stations within and adjacent to the study area. These sources of data are reasonably diverse and the processes used are conceptually well based and sufficient that the result of the analysis seems adequate and representative. A critical example showing this statement is reasonable is in regard to changes in watershed condition of the Sprague and Williamson Rivers (other than irrigated agriculture) and the net affect on streamflow. As these changes are progressive and cumulative, the net impact of these changes, if evident, would appear in the double mass and trend analysis that was completed comparing the calculated natural flow of the Williamson with the gaged natural flow of the Rogue. In that comparison, the trend in the normalized natural flow of the Williamson was shown to be consistent and comparable with the trend in the normalized annual flow of the Rogue.

Resulting elements of the simulation can be examined to determine if the response of the lake and resulting outfall is consistent with historical experience. One of the fundamental problems in this comparison, however, is that historical experience with the natural lake was during a series of years early in the 20th century when inflow to the lake was consistently about 1.35 times the average indicated for the period of interest in this study. An element examined for this consistency is the simulated water surface elevation of the lake, as shown on the following page, below. The trace of the time series for monthly average elevation of the water surface does not show any excursions or deviations that are inconsistent with historical experience.

Of particular interest regarding the outfall from the lake is the hydrographic trace for the last half of the period of interest. Results of the analysis show monthly average flows during the summers of 1992 and 1994 are as low as those encountered historically for the natural lake. Further, climatic factors that are causing the declining trend noted for inflow may be responsible for these secular low flows.



An examination of the hydrographic trace of the inflow and outflow for the last half of the period of interest illuminates the secular nature of the low mid-summer outfall from Upper Klamath Lake, as shown below. For years such as 1977, 1981, 1988, 1991, 1992, and 1994, significant late-spring seasonal snowmelt was not evident and the summer season natural outfall from Upper Klamath Lake was minimal. The secular minimum shown in 1992 indicates that *the mid-summer transit loss across the natural lake exceeds 800 cfs*, which is accountable to the nearly 130,000 acres of natural marshland and open water surface that were attendant to the natural lake.



Undepleted natural inflow to and outfall from UKL
natural lake conditions
7000
6000
5000
4000
3000
2000
1000
0
monthly avg flow cfs
inflow
outfall
1949-01
1951-01
1953-01
1955-01
1957-01
1959-01
1961-01
1963-01
1965-01
1967-01
1969-01
1971-01
1973-01
1975-01
1977-01
1979-01
1981-01
1983-01
1985-01
1987-01
1989-01
1991-01
1993-01
1995-01
1997-01
1999-01
water year month

Water balance of the natural Lower Klamath Lake –

The balance of the natural inflow to Lower Klamath Lake and attendant losses from the associated marshlands and the open water surface of the lake results in outfall from the lake at Link River. Inflow to the lake is therefore supporting these losses. The magnitude of each factor in the water balance may be described by examination of the resulting water-balance for the lake.

- *Losses from Upper Klamath Lake* –

For Lower Klamath Lake, the net evapotranspiration from attendant natural marshlands and the net evaporation from the open water surface of the natural lake comprise losses that are supported by the natural inflow to the lake from the Link River. Marshlands are solely comprised of lake wetland marsh that is continually inundated by storage in the natural lake. For the slightly less than 56,000 acres of marshland associated with the natural Upper Klamath Lake, these attendant losses averaged about 96,000 ac-ft per year for the 52 yr period of record. For the same period, net evaporation from the nearly 35,000 acres of open water surface of the lake averaged nearly 92,000 ac-ft per year.

- *Resulting water balance for Lower Klamath Lake*

The resulting natural outfall of Lower Klamath Lake is the consequence of total inflow and net loss. For natural lake conditions, the water balance for the average year, rounded to the nearest thousand acre-feet, below, is the result and includes an estimated measured pre-development ground-water accrual to the lake.

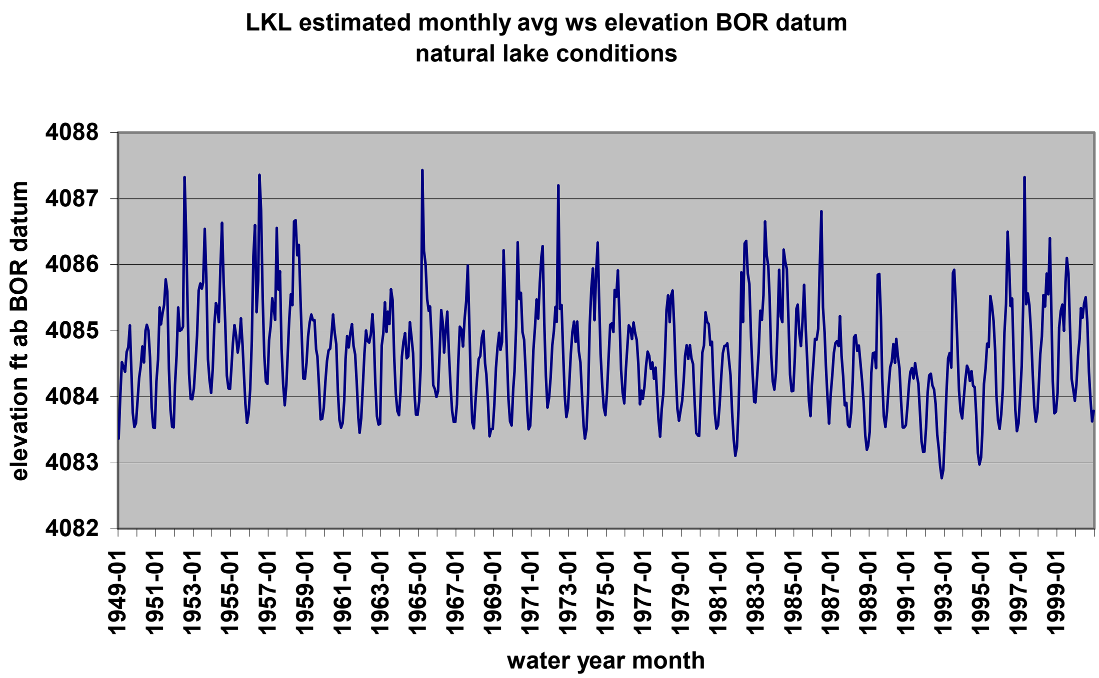
Average annual natural inflow………………………..	1,233,000 ac-ft
Average annual natural net loss ……………………...	188,000 ac-ft
Resulting average annual natural outfall..……………	1,045,000 ac-ft

Discussion –

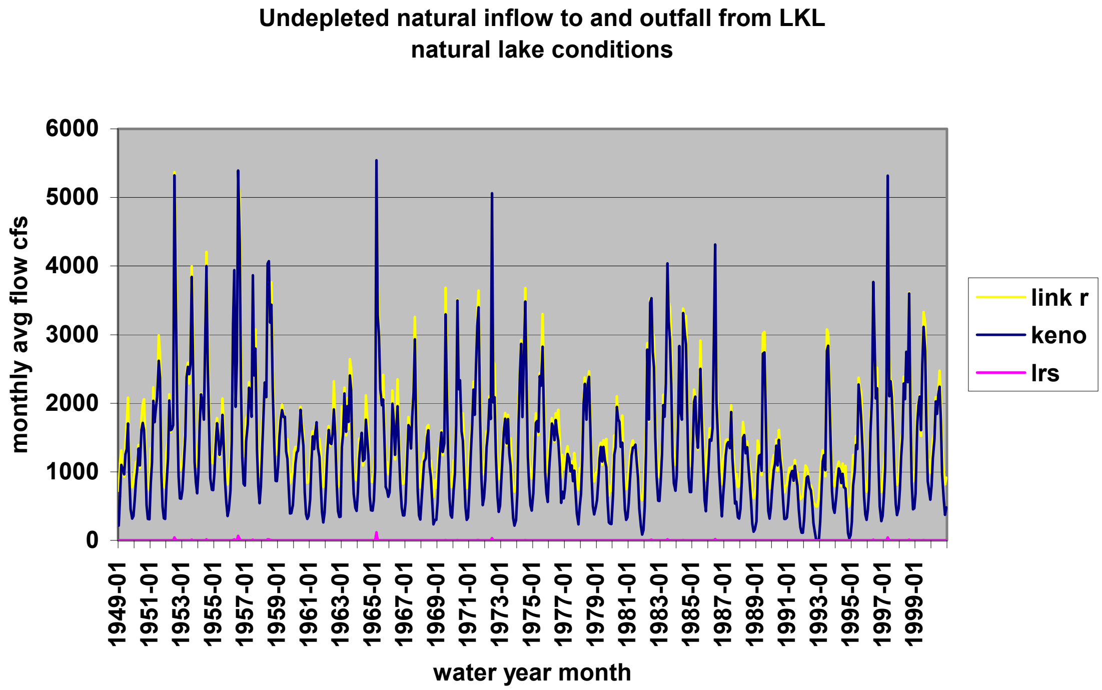
The process developed for the water budget for evaluating the undepleted natural outfall of Lower Klamath Lake appears to adequately account for factors that affected inflow to the lake, and for losses due to natural condition of the lake. Simulated outfall from Lower Klamath Lake was based on a conceptually straightforward explanation of the dynamic response of the lake to net inflow and storage within the lake as a natural water body. Records used in developing this analysis, which is an empirical assessment, were derived from both stream gaging flow histories, and from climatological records for stations within and adjacent to the study area. These sources of data are reasonably diverse and the processes used are conceptually well based and sufficient that the result of the analysis seems adequate and representative.

Resulting elements of the simulation can be examined to determine if the response of the lake and resulting outfall is consistent with historical experience. One of the fundamental problems in this comparison, however, is that historical experience with the natural lake was during a series of years early in the 20th century when inflow to the lake was consistently higher than the average indicated for the period of interest in this study. An element examined for this consistency is the simulated water surface elevation of the lake, as shown below. The trace of the time series for monthly average elevation of the water surface does not show any excursions or deviations that are inconsistent with historical experience.

Of particular interest regarding the water-surface elevation for the lake is the hydrographic trace for the last half of the period of interest. Results of the analysis show monthly average flows during the summers of 1992 and 1994 are as low as those encountered historically for the natural lake. Further, climatic factors that are causing the declining trend noted for inflow may be responsible for these secular low flows and the consequent secular low elevations evidenced in the water-surface elevation record.



An examination of the hydrographic trace of the inflow and outflow for the last half of the period of interest illuminates the secular nature of the low mid-summer outfall from Upper Klamath Lake and consequent outfall from Lower Klamath Lake, as shown below. For some years, especially 1981, 1988, 1991, 1992, and 1994, significant late-spring seasonal snowmelt was not evident and the summer season natural outfall from Upper Klamath Lake was minimal. The secular minimum shown in 1992 indicates that *the mid-summer transit loss across the natural lake exceeds 700 cfs*, which is accountable to the nearly 91,000 acres of natural marshland and open water surface that were attendant to the natural lake.



Conclusion –

This report has presented the results of a scientific investigation of natural streamflow in the Upper Klamath Basin of Oregon. Results of the analysis were based on a detailed assessment of losses to streamflow under present-day conditions, and the restoration and reconstruction of the natural streamflow that would have been inflow to Upper Klamath Lake under pre-development conditions. Not all present-day factors could be assessed regarding the change those factors have had on natural flow. The process, though, was sufficiently representative that natural inflow to Upper Klamath Lake could be assessed and losses incurred to that inflow evaluated for the lake as a natural water body. The reconstructed natural outfall from Upper Klamath Lake to the Link River was then routed through Lower Klamath Lake as a natural water body. The simulations of both lakes were based on the losses incurred from evaporation and marshes that affected the natural inflow, changes in storage from the resulting net inflow, and the dynamic response of the lakes to resulting changes in outfall to the Link River, for Upper Klamath Lake, and to the Klamath River at Keno, for Lower Klamath Lake. Results of these analyses were presented as hydrographic traces for monthly inflow, outfall, and monthly average water surface elevations of the lakes. Records used in developing these analysis were derived from both stream gaging flow histories, and from climatological records for stations within and adjacent to the study area, as well as historical documents regarding the natural condition of these lakes, and of the landscape under predevelopment conditions. These sources of data are reasonably diverse and the processes used are conceptually well based and sufficient that the result of these analyses seem adequate and representative.

References: Evapotranspiration and Consumptive Use Calculations

Allen, R.G., L. S. Pereira, D. Raes, 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.

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

Jensen, M.E., R.D. Burman, and R.G. Allen, 1989, Evapotranspiration and Irrigation Water Requirements, American Society of Civil Engineers, New York, New York, p 234.

Technical Release No. 21, Irrigation Water Requirements, September 1970, United States Department of Agriculture, Soil Conservation Service, Engineering Division.

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

References: 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., Kohler, Max A., Paulhus, Jospeh L. H., 1982, Hydrology for Engineers: McGraw-Hill Book Company, New York, New York. 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: Wood River Valley

Frank, F.J., and Harris, A.B, 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 Todd, R.M., 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 p.

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.

Lapin, L. L., 1983, Probability and Statistics for Modern Engineering: Wadsworth, Inc. (PWS Publishers), Belmont, CA, 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 University Press, Cambridge, 349pp.

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

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

Williams, G.P., 1983, Improper use of regression equation in the earth sciences: *Geology*, v. 11, no. 4, p. 195-197.

Williams, H. 1956, Crater Lake, on reverse of Crater Lake National Park and Vicinity, Oreg. 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.

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

References for Correlation Methods

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

Pollard, J. H., 1977, A Handbook of Numerical and Statistical Techniques with Examples Mainly from the Life Sciences: Cambridge University Press, Cambridge. 349pp.

Troutman, Brent M., and Williams, Garnett P., 1987, Fitting straight lines in the earth sciences, Chapter 7 *in* Use and Abuse of Statistical Methods in the Earth Sciences: Oxford University Press, New York. p. 107-28.

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

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 wind 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." Page 66-72 have some descriptions of lake area. Chapter IV LKL Williamson explorations Page 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, Chpt. 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 it's last historic high water level of 4064'". "…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', Tule Lake was about 10' 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, 122p.
Has discussion of preexisting wetlands, LRS, 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. Theer 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, Klocker Printery, Medford, OR, 59p. (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, USDI BOR, 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, 11p.
This provided information ion 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 LKL 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 SW 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 ion by boat from McCormaks 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 dyking 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 75tons."

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…" 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.

"Merril 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 USBR Files, 4p.
(Has info on Keno gage readings and LKL surface elevations, comments on letter indicate "…Keno gage readings represent very closely the lake levels…" Has figure with LKL elev 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), Western Historical Publication Company, Spokane, WA.

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

LINK: *Sacramento Bee* 2/26/1959
Article mentions that in Gatschet "of 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 2/26/59?) 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 the … 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 in American Archaeology and Ethnology, Vol. XXX, 338 pp.

LKL LRS: USBR, 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 LRS, shows profile along route of channel as well as River water elevations. Also shows RR connections across LKL July 1910 (on location map).

LKL: USBR, 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 re-construction 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 pers comm.).

LKL: Voorhees, I.S. 1913, History of the Klamath Project Oregon-California from May 1, 1903 to December 31, 1912, 175p.
Contains description of marsh lands, keno cut, natural reef at keno (4084'), and reference to Quiton's 1908 report.

LKL: Weddell, B.J. 2000, Relationship Between Flows in the Klamath River and Lower Klamath Lake Prior to 1910, Report for USDI FWS Klamath Basin Refuges Tulelake, CA. 10p.
Review of historical accounts. Describes early LKL 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, USBR. (Information on mapping LKL and reference to springs around LKL).

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

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

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

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

Other Maps Pertaining to Klamath River, Klamath Falls to Keno:

COPCO Drawing Numbers S(?)-4570 Upper and lower reefs ar Keno –cross sections reach between Stations 17+00 and 25+00 1927 JF Partridge;
S(?)-4571 Lower reef at Keno – cross sections reach between Stations 53+00 and 66+00, 1927, JF 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 GD Bowen;
F-5081-A Regulation dam site between Keno bridge and Keno plant, 1929, RT Warren;
F-5226 Properties along Klamath River, Klamath Falls to Keno, 1930, RT 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, JC 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 UKL 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 USBR 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.)

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

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

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

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

Grover, Nathan, C., McGlashan, H.D. and Henshaw, F.F., 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 314p.

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

Grover, Nathan, C., McGlashan, H.D. and Henshaw, F.F., 1923, Surface Water Supply of the United States 1919 and1920, Part XI. Pacific Slope Basins in California, USGS Water Supply Paper 511, Government Printing Office, Washington 456p.

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

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

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

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

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