Klamath Straights and the reclaimed southerly expanse of Lower Klamath Lake. Photo by Delbert Smith, color by T. Perry.

Undepleted Natural Flow of the Upper Klamath River
A Summary Report

Part 2: Natural Inflow to, Natural Losses from, and Natural Outfall of Lower Klamath Lake to the Klamath River at Keno

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November 7, 2003
Draft

Introduction –

This report summarizes Part 2 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 of Part 2 are related to 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 which is the inflow to Lower Klamath Lake. This study integrates an evaluation of changes to the natural watershed and natural condition of Upper Klamath Lake with an evaluation of the natural system of Lower Klamath Lake and the consequent natural outfall to the Klamath River at Keno. The assessment of Upper Klamath Lake and the resulting outfall to the Link River due to the pre-development natural aspect of Upper Klamath Lake is considered in Part 1. 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 Klamath River at Keno are described.

Present-day view of Lower Klamath Lake, and changes from predevelopment conditions –

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. For Lower Klamath Lake, natural inflow to the lake is comprised solely of the natural outfall from Upper Klamath Lake (see Part 1) and measured ground-water inflow from springs. The natural condition of Lower Klamath Lake, however, was a complex of marshes and open water. Included in this system is the elongated Lake Ewauna which forms the head of the Klamath River, and the winding channel of the Klamath River which issues from the lake. This channel follows a generally sinuous southwesterly course 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 Lake Ewauna were controlled by a natural basalt reef 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, also carried water out of the lake system. This diversion of the natural flow of the Klamath was to the southeast and was tributary to the Lost River, thence becaming inflow to Tule Lake in an adjacent closed basin that lay east of Lower Klamath Lake.

Beginning in 1905, the reclamation of Lower Klamath Lake began for recovery of the land to agricultural uses. In 1917, with closure of the Klamath Straights, 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.

Hydrologic aspects of the predevelopment Lower Klamath Lake –

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 open water surface evaporation. 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 overflow through the Lost River Slough and flow out of the Klamath basin and into the closed basin of the Lost River. 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. For the natural Lower Klamath Lake, the following are noted:

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

General methodology for simulating Lower Klamath Lake –

Because the natural inflow to Lower Klamath Lake has been determined, all of the other natural factors affecting the lake as an hydrologic system must be evaluated and implemented in a simulation. Conceptual development of the simulation must consider factors affecting outflow from the lake such as evapotranspiration from natural marshlands associated with the lake, evaporation from the open water surface of the lake, elevation of the lake water surface and resulting outfall from the lake, and water resident in storage in the lake. 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.

Accounting for these factors is straightforward. Relationships for gage height of the water surface of the lake versus storage in the lake were developed from published data generally for the pre-dam 1904 to 1918 period. A discharge-rating curve was also developed from these same data where the relationship for monthly total outfall from the lake to the Klamath River at Keno may be computed from the determined monthly average water surface elevation of the lake. 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 for the selected 52 yr period of record. The resulting records of interest are for natural outfall from the lake to the Klamath River at Keno, and monthly average elevation of the water surface of the lake.

Evaluation of natural losses from Lower Klamath Lake –

Evaporation from the open-water surface of the lake and marshland evapotranspiration were estimated using meteorological data that were available and reconstructed for several nearby data collection platforms. Water-surface evaporation was calculated using Hargreaves' equation for daily incremental data, where such data were available, or for monthly data where data records were reconstructed for average monthly temperature and precipitation if daily data were unavailable. The calculated values for *Hargreaves* evaporation on a monthly basis were adjusted to approximate the evaporation rate in ft/month from the open water surface of the lake. Net evapotranspiration from marshland associated with Lower Klamath Lake was calculated using the same modified SCS Blaney-Criddle model used in analyses for the Sprague and Williamson Rivers. Meteorological stations included two primary stations and three supporting stations for the completion of the evaporation the transpiration analyses.

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.

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

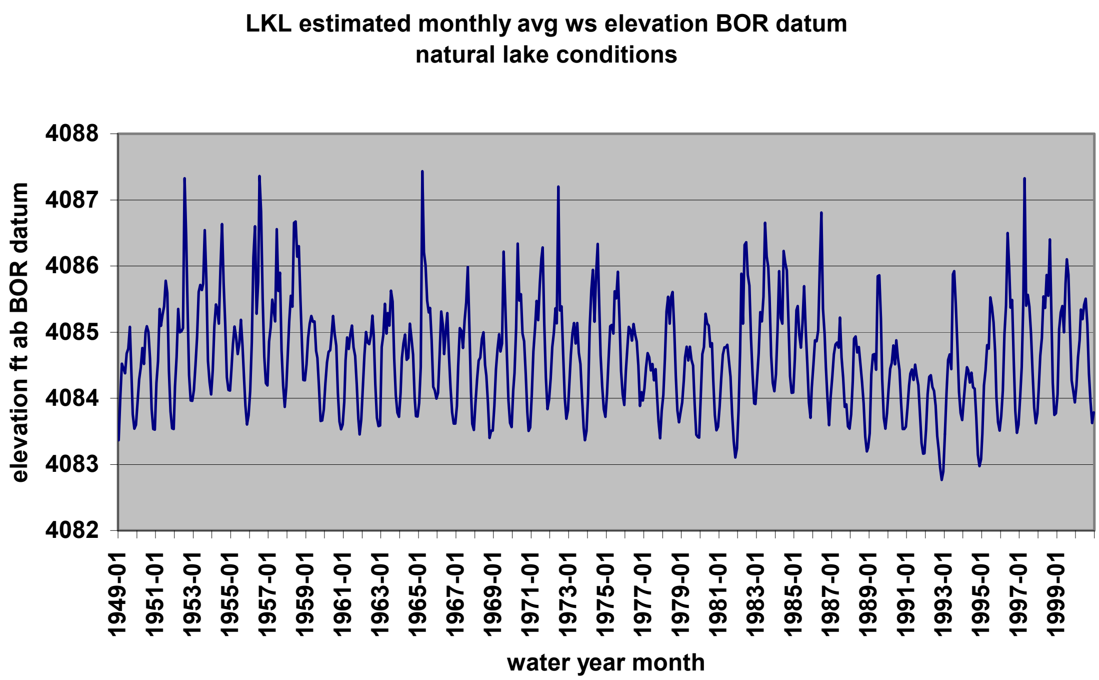
Resulting average annual natural outfall..…………… 1,045,000 ac-ft

Discussion –

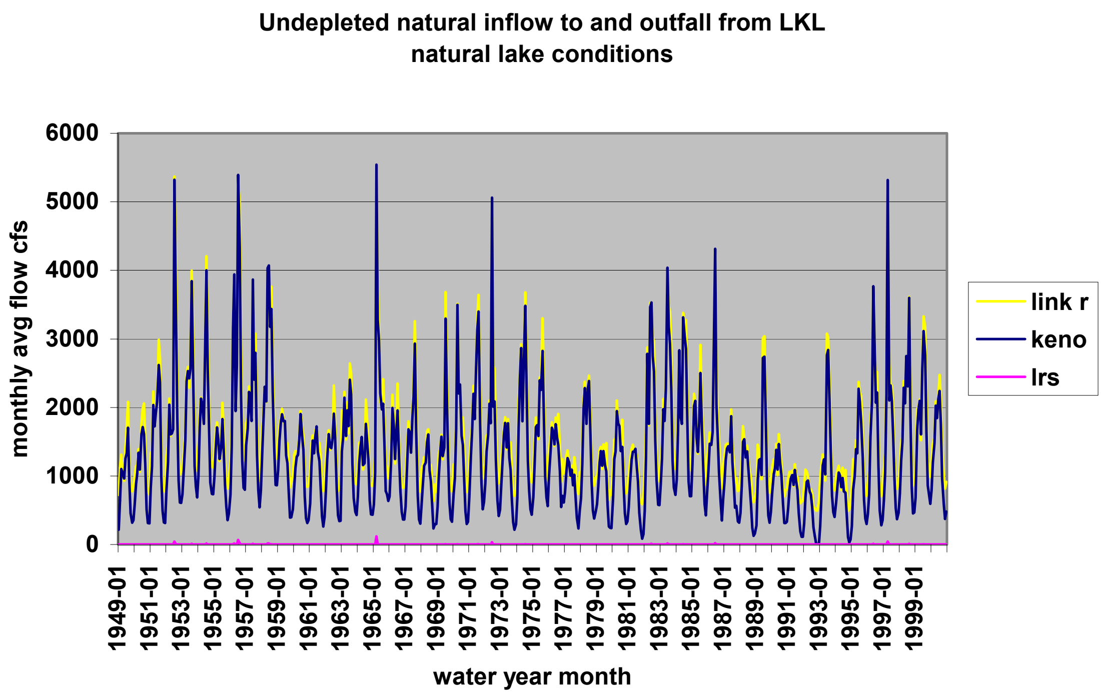
The process developed for the water budget for evaluating the undepleted natural outfall of Lower Klamath Lake appears to adequately account for factors that affected inflow to the lake, and for losses due to natural condition of the lake. Simulated outfall from Lower Klamath Lake was based on a conceptually 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 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 (see Part 1) 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 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.


Undepleted natural inflow to and outfall from LKL
natural lake conditions
monthly avg flow cfs
6000
5000
4000
3000
2000
1000
0
water year month
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
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