
Wocus Marsh. Photo and color by T. Perry.

Undepleted Natural Flow of the Upper Klamath River
A Summary Report

Part 1: Natural Inflow to, Natural Losses from, and Natural Outfall of Upper Klamath Lake to the Link River

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Introduction –

This report summarizes Part 1 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 1 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. 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. A similar assessment of the resulting losses to the flow at Keno due to the pre-development natural aspect of Lower Klamath Lake is considered in Part 2. 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.

Present-day view of the Upper Klamath Basin, 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. 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 1. The description given with the figure caption explains the conceptual process required to estimate pre-development natural flow.

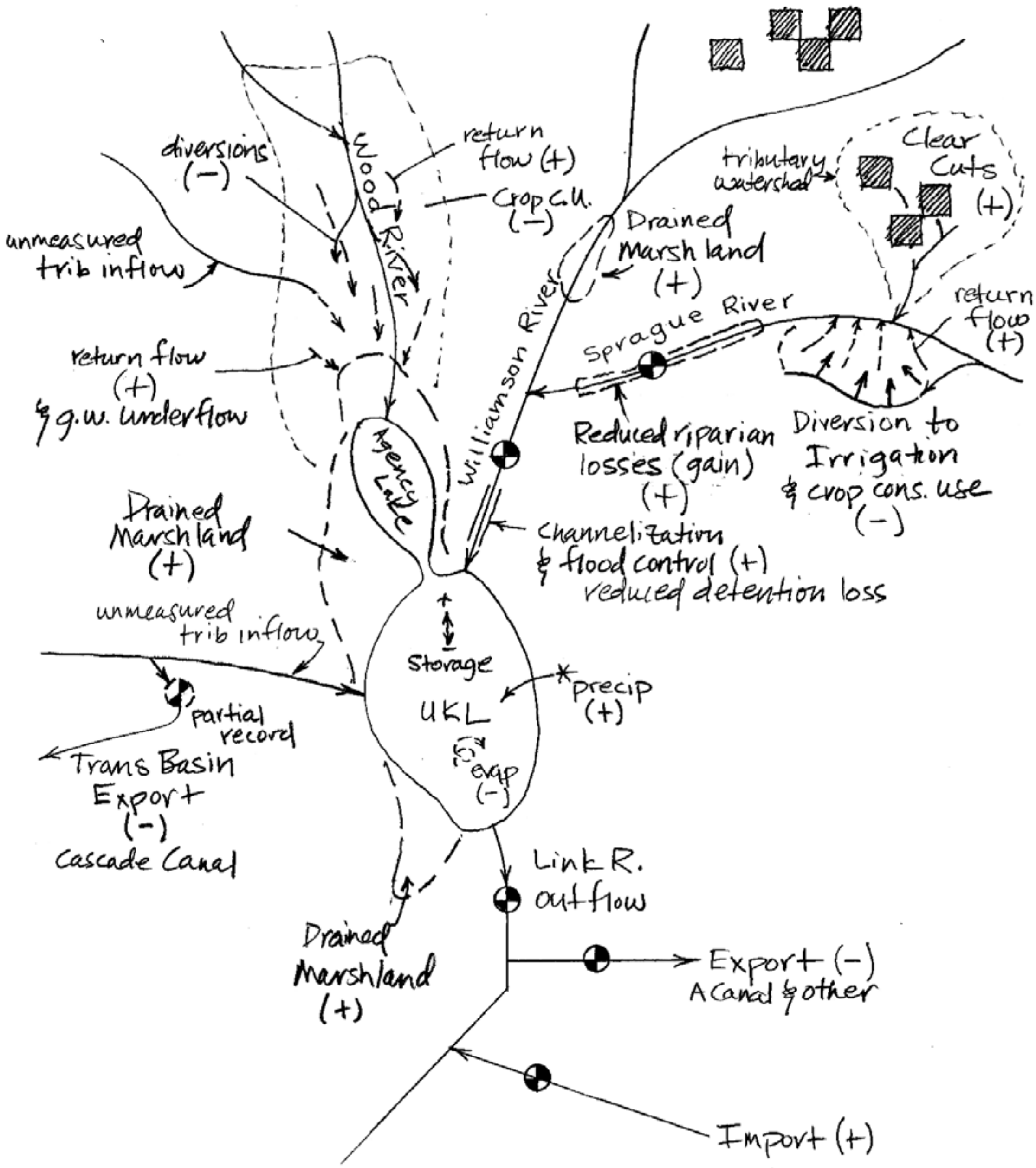


Figure 1. Cartoon of present-day watershed of Upper Klamath Lake. For a generalized view of the water budget shown in this conceptual view, changes in streamflow due to current conditions are indicated by (+) for gains in flow or (-) for losses in flow. As a general rule for the water budget, + and – 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.

General methodology for determining the natural inflow to Upper Klamath Lake –

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.

Statistical methods used in reconstruction of supporting records –

Reconstruction of missing values in meteorological and gaging station records of interest was accomplished through correlation analysis by using a variety of linear and curvilinear line-fitting procedures. The implemented methods are similar to those used by Ried, et al. (1968), for the extension of streamflow records in Utah. Given a sufficient number of concurrent values between two records of which one is missing some values, the objective of these procedures is to then fit the best line of correlation for recovery of the most representative and likely variability estimated to be existent in the missing portion of the record being reconstructed. Records longer than about 12 years were reconstructed on a concurrent month-by-month basis with another similar, nearby, yet generally longer-term record and reassembled into the resulting synthetic time series representing for the longer-term gage record. Explained variability, given by the sample coefficient of determination, r^2, is used as a guide, but not as a rule, in the assembly of such reconstructed records.

Reconstructions accomplished in this study are for gaged flow records of presently occurring natural undepleted flow, and for meteorological records used in aspects of the study. For some streams within the Wood River Valley, reconstructions were accomplished by adjustment of watershed characteristics and correlation of the seasonal character of gaged flows with monthly and seasonal total precipitation to produce a reconstructed record. For some flow records, estimated monthly flows determined from daily flows and incidental measured flows were correlated with monthly flows gaged in adjacent watersheds so that a representative time-series was developed which reproduces the estimated monthly flow and seasonal-flow character likely to be seen for these streams.

<u>Water-budget approach for Sprague and Williamson Rivers</u> –

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. Adjustment of the gaged record to natural conditions must also account for the losses that would have been incurred from natural riparian marshlands that were reclaimed for irrigation uses. The water budget for natural flow at the gage is straightforward:

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

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.

<u>General methodology for simulating Upper Klamath Lake</u> –

Once the natural inflow to Upper Klamath Lake has been determined, all of the 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 open water surface area of the lake is conceptually fixed and does not vary. For Upper Klamath Lake under predevelopment natural conditions, the following were noted or conceptually developed from materials that were researched:

Lake natural wetland marsh area……….………………………... 53,306 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)

In addition, approximately 9210 acres of emergent marsh were associated with Upper Klamath Lake. Within the conceptual view of the lake, this emergent marsh causes a direct depletion of inflow to the lake.

These listed factors are somewhat simply interrelated and accounting for them 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 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 for the selected 52 yr period of record. The resulting records of interest are for natural outfall from the lake to the Link River, and monthly average elevation of the water surface of the lake.

Evaluation of natural losses from Upper 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 Upper Klamath Lake was calculated using the same modified SCS Blaney-Criddle model used in analyses for the Sprague and Williamson Rivers. Meteorological stations included four primary stations and one supporting station for the completion of the evaporation the transpiration analyses.

Evaluation of inflow data –

Natural flow data developed by water budget assessments of the Sprague and Williamson Rivers were evaluated using double-mass analysis coupled with an integrated trend analysis. Through use of this technique, results may be immediately evaluated for representative recovery of variability and comparability with another stable record that is forming the basis for the comparison. Comparative differences may be assessed immediately for any single month, and veracity of the achieved results verified through evaluation of the reconstructed annual time series. Because these records are restored to natural flow based on an empirical assessment of agricultural uses and reclaimed marshland losses, trend assessment and double-mass analysis are the most immediate means to determine the representative value of these restored records. Evaluation of results in this manner was accomplished only for those specific inflow records to Upper Klamath Lake that were restored to undepleted natural flow, or for the comparison of specific gaged records and related meteorological records forming the basis for evaluating reconstructed natural streamflow. Through this process, reconstructed natural flows derived for this study were shown to be representative and comparable with other available gaged natural flow records.

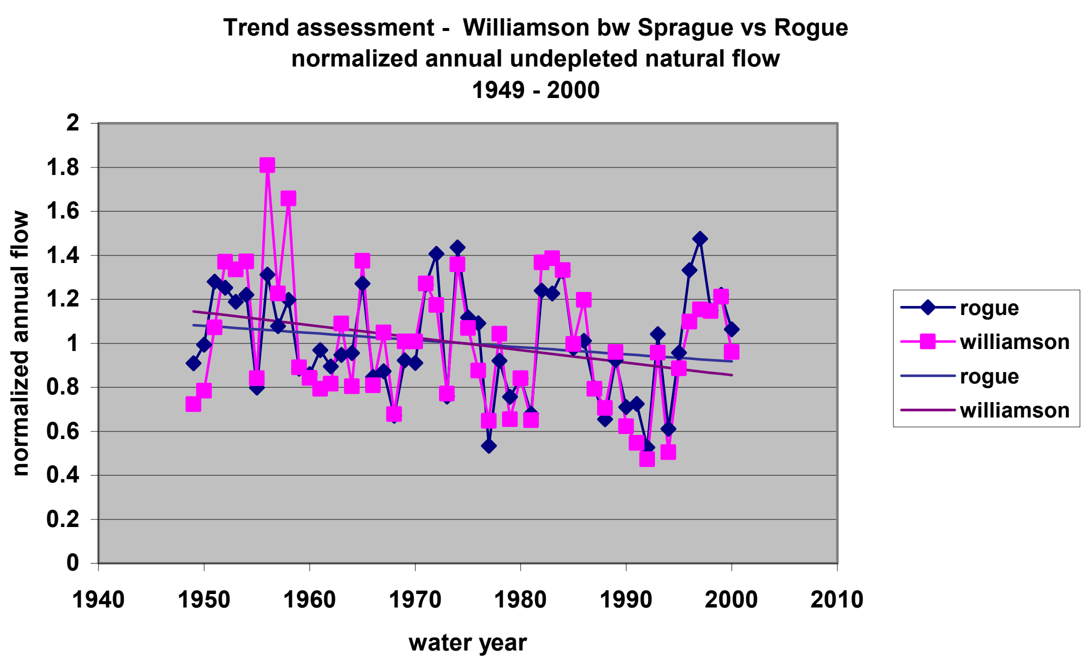
Because there are no long-term, natural-flow stream gages in the upper Klamath basin, the comparison of developed natural flow at specific inflow nodes must be made with natural flow gages in an adjacent basin. Only one such gage is present, 14328000 Rogue River above Prospect, for comparison with natural flow histories that have been developed for the upper Klamath basin. The basic premise of the comparison is rather simple, namely, that climatic variability between the upper Rogue basin and the area of interest for the upper Klamath basin is consistent and within a larger, dominant, regional climatic regime. However, the gage chosen within the Rogue basin must be checked, itself, to determine the veracity of this assumption both with regard to natural flow conditions, and climatic consistency. Albeit there are watershed changes due to logging in the upper Rogue basin, the comparison of this gage may be made, nonetheless, with another similar gage which may, or may not, have similar watershed changes. For well managed forest practices, these watershed changes are not noted as catastrophic to the watershed and pose much less impact than catastrophic events such as fire. Further, long-term climatic records such as those for precipitation at Crater Lake National Park and at Prospect were used to cross-refer and check consistency in evidence of trend and of regional climatic consistency.

<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 River –

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 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.

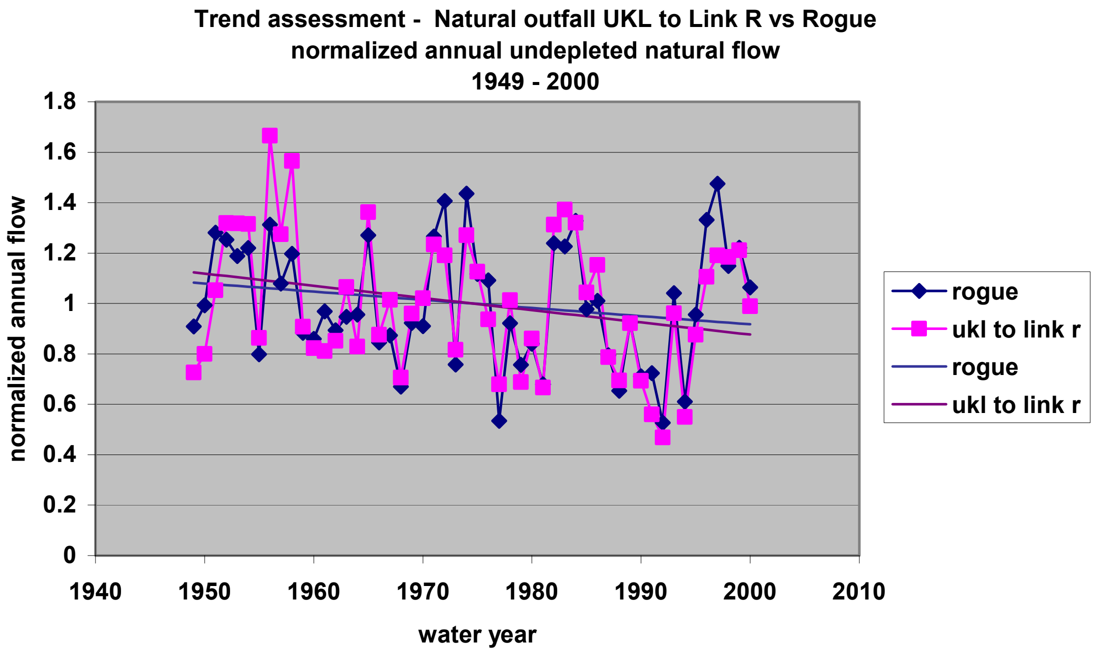
Resulting water balance for Upper Klamath Lake –

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.



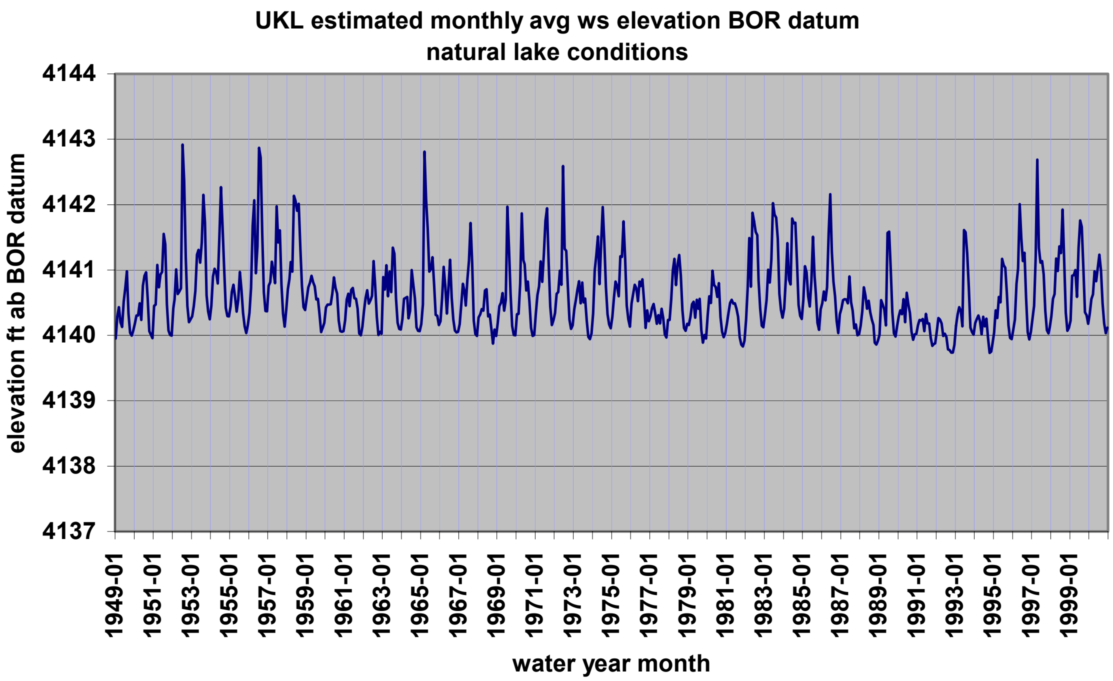
Discussion –

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.

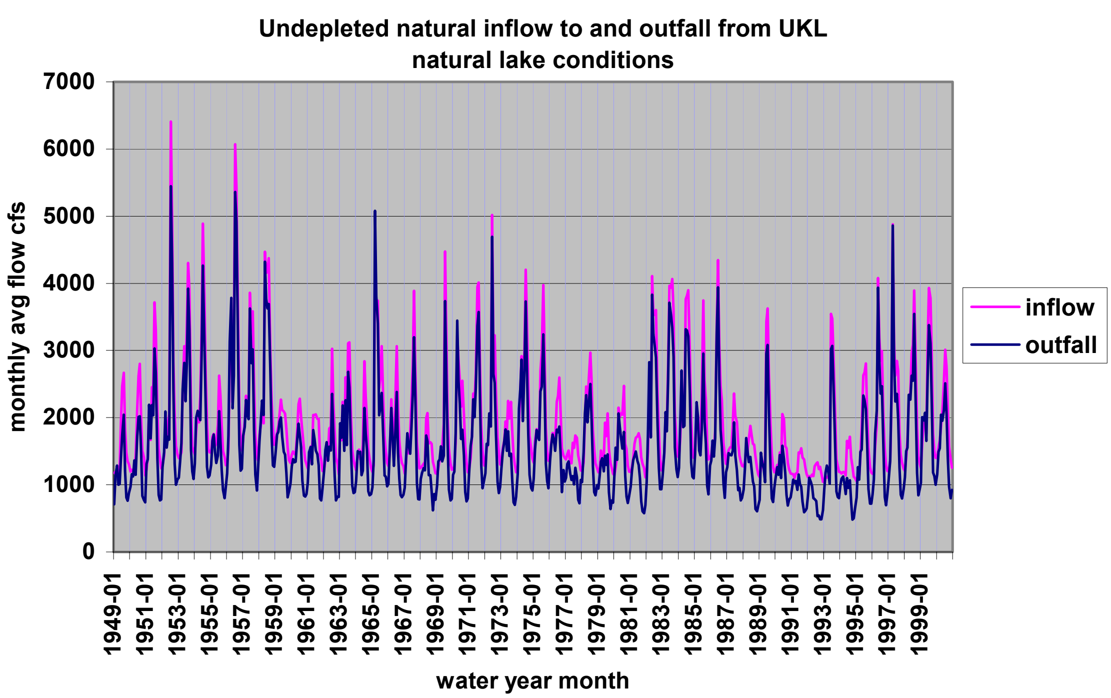
Resulting elements of the simulation can be examined to determine if the response of the lake and resulting outfall is consistent with historical experience. One of the fundamental problems in this comparison, however, is that historical experience with the natural lake was during a series of years early 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.



Cited material –

Ried, 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.