An Assessment of the Effects of Klamath Marsh On Water Rights Above and Below Klamath Marsh

Prepared For

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Summary:

The Klamath Marsh plays an integral role in the hydrology and therefore water use in the Williamson River basin. This study investigated the relationship between Klamath Marsh water levels and discharge in the Williamson River above and below the marsh. The impetus for this study was to evaluate if water users with senior rights downstream of Klamath Marsh could benefit from calls on water use upstream of the marsh having junior water rights.

Using gage and miscellaneous stage measurements, no relationship was found between marsh levels and downstream accretions (spring and groundwater flows) in the Williamson River between Kirk and Chiloquin. This would indicate that increasing the marsh stage (water levels) would not result in higher downstream accretions. However, surface water discharge (both at Kirk and Chiloquin), were dependent on the marsh stage, if the stage was near the top of the natural basalt dam, located near the marsh outlet just upstream of Kirk (4512.80' mean sea level, MSL). Above this stage, water spills over the basalt sill and downstream discharge increases with marsh water levels. Below this stage, discharge at Kirk is zero and discharge at Chiloquin is not related to marsh stage.

Using a mass balance analysis, the maximum stage the marsh could be raised for each month through elimination of all upstream irrigation was estimated. A conservative assumption in the analysis (i.e., the assumption favors increases in marsh levels with inflows) was that evapotranspiration (ET) rates would not increase with increased marsh water levels. From this analysis, the maximum monthly increase for the year was calculated to occur in May and corresponded to 0.28 feet. However, the maximum increase for August was only 0.03 feet. In other words, for the month of August, unless the marsh water level was within 0.03 feet of the basalt sill at Kirk, no increase in downstream flow would result by either surface or sub-surface means from elimination of all upstream irrigation. In reference to marsh levels between 1992 to 1997, no downstream benefit would have occurred from July to October through the elimination of all upstream diversions. For two very dry years in this period, 1992 and 1994, no downstream benefit would have occurred from June to October. Using this analysis and the stated assumptions, some partial increase in downstream flows may have been realized for April and May.

Using regression analysis, the relationship between Williamson River inflows and Klamath Marsh stage was found to be poor ($R^2 < 0.33$). Given that downstream accretions (groundwater outflows) do not change with marsh levels as previously mentioned, this may indicate that ET rates fluctuate with inflows and marsh levels. In the mass balance analysis, this would reduce the calculated maximum increase in stage and therefore overstate the benefit to downstream flows (e.g., increases in downstream discharge in April and May from zero upstream irrigation). It may also indicate that as with many marshes, the groundwater inflows control the marsh stage as opposed to surface water inputs.

A hydrograph comparison between Williamson River inflow and outflow supports the latter as there is no obvious relationship between peak flows into and out of the marsh.

Regression of monthly mean flows above and below the marsh show a weak relationship ($R^2 < 0.61$) with residuals being heteroscadastic (i.e., poor fit), although, there is a positive trend. However, the trend of increase in outflows with inflows is probably indicative of stream response at both locations to basin wide conditions (i.e., groundwater flow), as opposed to a causal relationship between marsh surface water inflows and outflow.

Taken collectively, these results indicate that the augmentation of downstream flows by control of upstream irrigation is not probable due to the hydrologic properties of Klamath Marsh, even when considering the elimination of all upstream irrigation. Overall, basin conditions appear to control the marsh water level via groundwater inputs to the marsh. Augmentation of any surface water inputs is likely to result in increased marsh ET, bank storage, and a negligible increase in marsh stage. Even assuming marsh ET does not increase, the estimated increase in marsh stage for each month would not result in increased downstream flows, unless the marsh stage is near the top of the basalt plug at the marsh outlet. This water level is not likely during summer months of dry years. Furthermore, for partial calls on upstream water users, the net increase in marsh stage would be even smaller and the required water level for downstream benefit to occur would be higher (i.e., closer to the basalt sill).

Introduction:

Marshes play an intricate and complicated role in the hydrology of streams and basins in general. In terms of a streams hydrograph, marshes generally act as low pass filters, reducing peak flows and augmenting low flows via water storage capacity in the soil matrix (bank storage). In many cases marshes are located at or near groundwater discharge zones and, as such, are heavily influenced by groundwater inflow. Preliminary studies of the Klamath Marsh have shown that it may also be dominated by groundwater inflows (Norvelle et. al., 1981). Marshes also tend to have high evapotranspiration (ET) rates, which, under certain specific vegetation conditions, can exceed evaporation rates from a free water surface (Norman et. al, 1983). All of these conditions, (high ET rates, large groundwater inputs, and considerable bank storage capacity) complicate the hydrologic response of a stream located below a marsh to climatic conditions. These same conditions also complicate the streamflow response below a marsh to upstream flow variations occurring from land use practices. Finally, the general lack of defined river channels within marshes further obscures the relation between flows into and out of marshes.

This study investigates the hydrologic relation between the Klamath Marsh and streamflow in the Williamson River above and below the marsh. The object of the study is to evaluate the potential for flows upstream of Klamath Marsh, increased through reduction of irrigation, to increase discharge downstream of the marsh. More specifically this study evaluates if water users downstream of Klamath Marsh with senior rights can benefit from calls on water use upstream of the marsh with junior water rights.

Background:

Study Area:

The study area consists of the upper Williamson Basin defined as the 1417 square miles delineated above the Williamson River confluence with Sprague River in South Central Oregon (Figure A). Most of the basin (1290 square miles) is contained in a plateau that rises abruptly to the far west where the plateau meets the Cascade Mountains and to the east where the plateau meets an unnamed mountain ridge containing Yamsey Mountain and Hamilton Butte. The plateau rises slowly to the north and south where the divides with the Deschutes and Sprague basin are defined, respectively, by low elevation buttes.

Klamath Marsh, the main hydrologic feature in the basin and key focus in this study, occupies a topographic low near the center of the basin. The Williamson River, Big Springs Creek and Spring Creek are the other significant hydrologic features in the basin as is Crater Lake (Mt. Mazama) which lies due west of Klamath Marsh. To the southwest of the marsh the plateau falls abruptly approximately 300 feet to a lower plain where Spring Creek is located. This lowland contains the remaining 127 square miles of the basin, but plays a significant role in the hydrology of the basin.

In general terms, the soils west and northwest of Klamath Marsh consist of deep highly permeable pumice ash soils which give way to basalt on the eastern slopes of the Cascades. Soil depths range from only a few feet at the eastern edge of Klamath Marsh to over 75 feet along highway 97 (Norvelle et. al. 1981). To the east, northeast, and

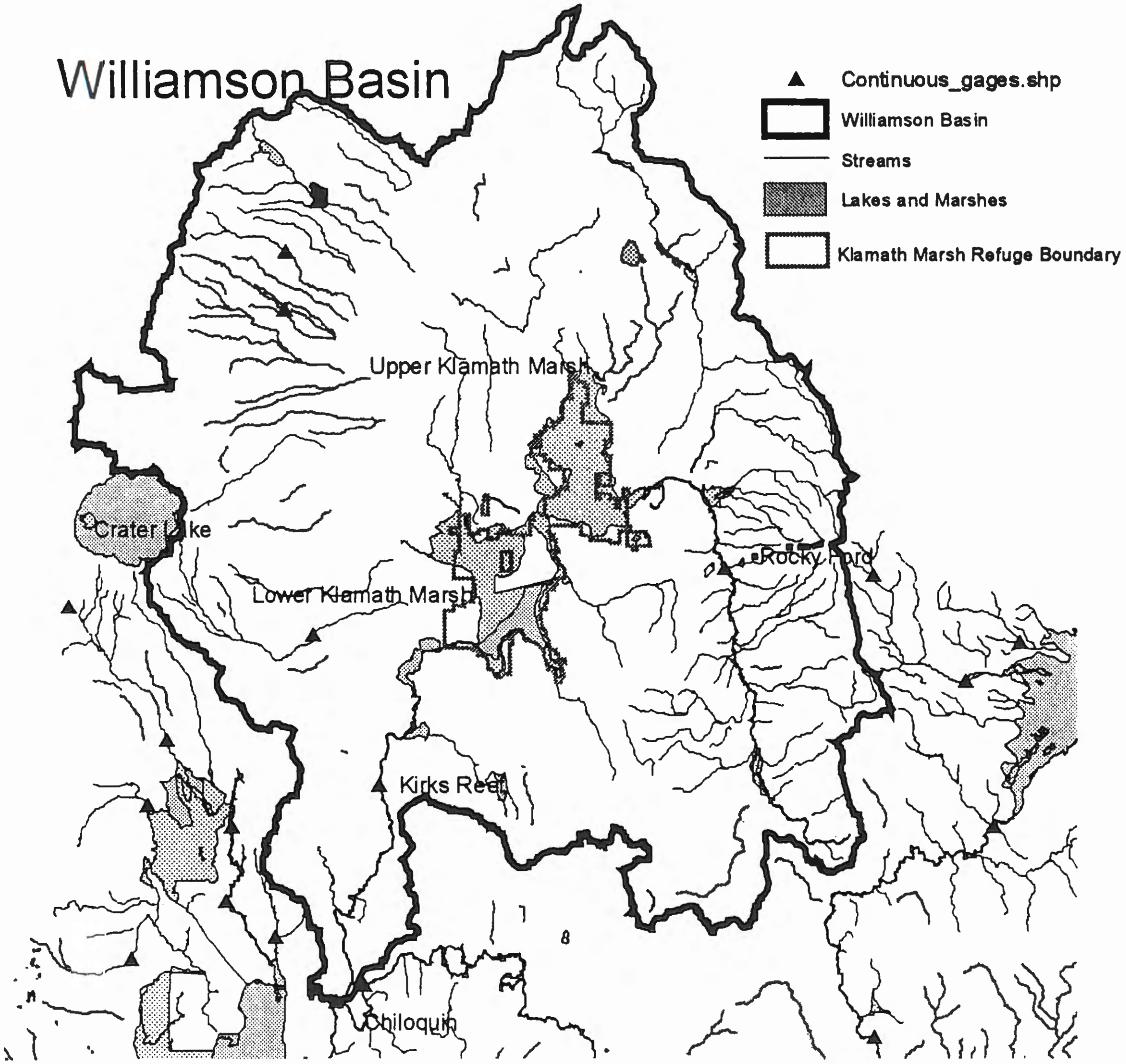

Williamson Basin
Continuous_gages.shp
Williamson Basin
Streams
Lakes and Marshes
Klamath Marsh Refuge Boundary
Upper Klamath Marsh
Crater Lake
Rocky Ford
Lower Klamath Marsh
Kirks Reef
Chiloquin

Figure A

southeast of Klamath Marsh, shallower pumice ash soils overly less permeable basalt. Klamath Marsh and the Williamson River valley above the marsh have lower permeable alluvium deposits consisting of peat and diatomite, underlain by pumice, then, silt, sand, clay, gravel, and ash (Norvelle et. al., 1981, State Water Resources Boards, June 1971).

The climate in the basin can be classified as semiarid, with dry, mild summers and wet, cold winters. Precipitation falls mostly in the winter between November and March. The highest precipitation occurs along the peaks of the Cascades, and diminishes towards the central basin before increasing near the Yamsey Mountain ridge to the east.

Surface Water:
The Williamson River is the main stream in the basin and originates from springs just east and south of Taylor Butte. From its source the river flows almost due north for 35 miles then turns west for five miles where it historically spread over a delta and emptied into Klamath Marsh. This reach of the river above Klamath Marsh is defined as the Upper Williamson River (UWR) for this study. Most of the tributaries to the Upper Williamson are ephemeral, with flows occurring during spring runoff. The average annual runoff for the Upper Williamson is 66,000-acre feet (ac-ft) or 91 cubic feet per second (cfs).

Klamath Marsh is shaped somewhat like an hourglass, with its narrowest point located where Military Crossing road crosses the marsh. This road effectively dissects the marsh into two sections (upper and lower), which, however, are still connected both hydrologically and hydraulically. The lower section consists of the more permanent marshland, defined as areas consistently inundated with water. While the upper section in more seasonal marshland, defined as areas seasonally inundated with water. Estimated area for the marsh ranges from 30,000 (Clyde, Criddle, and Woodward, Inc., 1976) to 45,000 acres based on USGS topographical maps. However, the entire Klamath Marsh Lowland (KML) is over 60,000 acres (Adkins, 1970), which includes Solomon flats to the south of the marsh.

No natural river channel exists in either the upper or lower sections of the marsh. However, with reclamation efforts by early farmers, drainage canals were built into the upper section to help drain the marsh after spring runoff for livestock and then to supply the same areas with water for pasture during the summer months. The canal system begins at the historic river delta near the old Kittredge ranch, now part of the US Fish and Wildlife Services Klamath Marsh National Wildlife Refuge. From this location, the Cholo and Kirk ditch distribute Williamson River water to the dryer southeast part of the upper section. In addition, the Twin Bridges canal diverts water north towards Sagebrush point before turning west across the marsh to The Peninsula, approximately two miles northeast of Military Crossing. From The Peninsula water can be supplied into the northwest area of the upper section via a levee or across the open marsh (i.e., no channel or canal is present) south towards Military Crossing. The northwestern area of the upper section is also supplied water by Three Creeks, while the northeastern area of the upper section is supplied water by God, Mosquito, and Lane creek. All of these creeks are ephemeral. The Kirk ditch also flows west across the marsh where it ends near Military

Crossing. From Military Crossing south approximately 10 miles to Wocus bay is the wetter permanent area of the marsh where no artificial or natural channels are present. Located in the southern most part of the Refuge, Little Wocus and Wocus bays contain the wettest portion of the entire marsh with approximately 1000 acres of relatively open unvegetated water (Bienz, 1981).

In the southernmost section of the marsh, to the west of Little Wocus bay, the Williamson River again appears. From Little Wocus bay to the Kirk gaging station, the Williamson River meanders through level open land for about 14 miles, widening into an open pond at Solomon Flat (Norvelle et. al. 1981). From here the river flows over a basalt plug or sill, past the Kirk gaging station and continues towards Klamath Lake. Average annual discharge at the Kirk gaging station is 161 cfs or 117,000 ac-ft. It should be noted that in 24 of the 41 years on record (1954-1995) there was no flow below the marsh in late summer to early fall. This is due to the water level falling below the lip of the basalt sill at the KML outlet.

To the west of the Refuge in the lower section of the marsh, is dryer meadowland/pasture irrigated from springs, wells, and Big Springs Creek all fed by groundwater from the east slopes of the Cascades. Big Springs Creek, a short creek that originates from springs to the northwest of Lenz, can be a major source of inflow to the marsh. During the spring of wet years, it may even exceed the inflow from the Williamson River (Norvelle et. al. 1981). However, Leonard and Harris (1974) noted the creek was dry from 1931-1951. In addition, the average daily flow between May of 1992 and October of 1995 (a relatively dry period) was only 3.3 cfs. Records also show low-flow discharge values range from 20-80 cfs between 1956 and 1978. In general, flows in Big Springs creek follow ground water conditions in the basin (Norvelle et. al 1981)

Further to the west and northwest, several streams originate on the eastern slopes of the Cascades then disappear as they flow across the deep highly permeable pumice plain towards the marsh. These include Miller, Sink, and Cottonwood creek to the northwest of the marsh, and Bear, Scott and Sand creek directly west of the marsh. None of these creeks presently reaches the marsh as surface flow.

Located on the lower plain, below the Klamath Marsh lowlands and downstream of the Kirk gauging station, Spring Creek joins the Williamson River. Spring Creek originates from groundwater via springs and, although the drainage area is only 9 square miles, flows consistently at around 300 cfs or 217,000 ac-ft. This represents roughly two-thirds of the annual flow of the Williamson above the Sprague confluence (470 cfs, 341,000 ac-ft), and during low flow months contributes almost the entire flow of the river (State Water Resources Boards, June 1971).

Ground Water:

Groundwater recharge occurs in the high precipitation, highly permeable areas on the flanks of the Cascade Mountains and to a lesser extent in the northern, eastern and southern margins of the basin which have less permeable soils and receive less precipitation. The State Water Resources Board Report of the Klamath Basin (1971) estimated that roughly 900,000 acre-feet of water per year is recharged into the Williamson sub-basin. Some of this recharge is lost to adjacent basins (Sprague, Wood, and Klamath Lake), but approximately 500,000 acre-feet per year resurfaces within the basin at discharge zones (State Water Resources Boards, June 1971). Klamath Marsh, which occupies a topographic low near the center of the basin, along with the Williamson River Valley, Big Springs Creek and Spring Creek, act as the major discharge zones for groundwater in the basin (Norvelle et. al 1981, State Water Resource Board, 1971). Norvelle et. al. 1981 calculated a rough estimate of the average groundwater discharge into the marsh at 430,000 acre-ft. By comparison, the estimated natural average annual runoff of the Williamson river into Klamath Marsh is only 66,000 acre-ft, or 15% of the total groundwater inflow to the marsh.

Irrigation:

Most of the irrigated lands in the Williamson basin are in the Williamson River Valley and in the Klamath Marsh Lowlands. According to the Oregon Water Resources Department's claims and permits database, there are roughly 15,000 acres of irrigation rights above Klamath Marsh and 44,300 acres total in the basin upstream of the Kirk gauging station. Approximately 27,600 of these irrigated lands are within the Klamath Marsh Lowlands. The only other irrigated land (roughly 3000 acres) occurs between Spring Creek and Chiloquin, thirteen miles downstream of Klamath Marsh. The total OWRD claimed and permitted irrigated acres for the Williamson basin is therefore 47,300 acres. However, according to the USGS's "Estimated Water Use and General Hydrologic Conditions for Oregon, 1985 and 1990" only 27,000 acres were being irrigated in 1990. The difference between the two numbers can be attributed to crop rotation and water use below the claimed and permitted amount.

Approach:

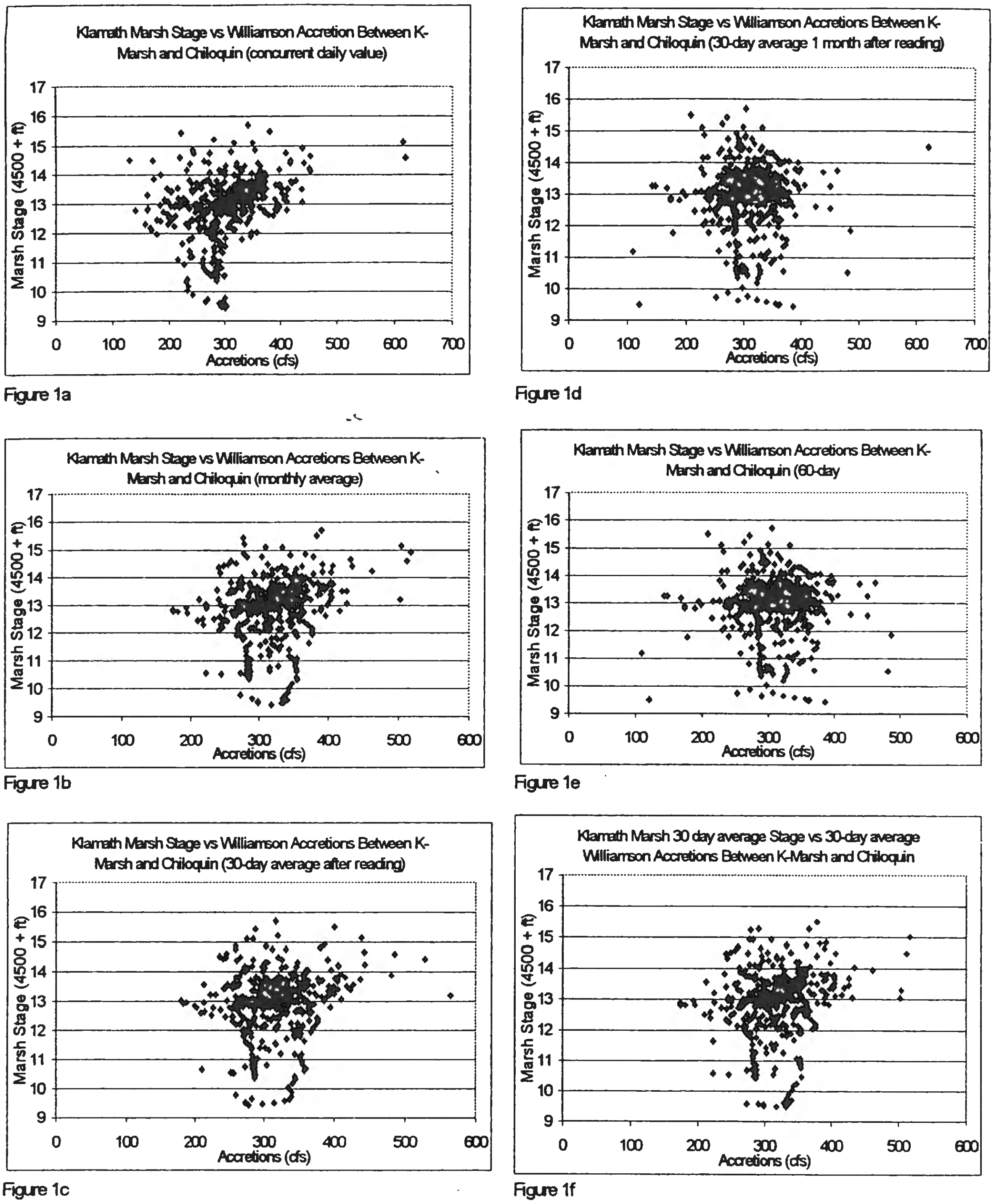
The primary goal of this analysis was to investigate if marsh levels could be raised and flows downstream of the marsh increased through the control of irrigation from surface water inflows within and into the Klamath Marsh. To address this question, regression analysis was used to investigate the relationship between flows above and below the marsh with marsh water levels (stage). Regressions were applied to data collected from USGS/OWRD stream gage sites at Rocky Ford (above the marsh), Kirk (just below the marsh), Chiloquin, and miscellaneous marsh stage measurements collected by the USGS/USFWS near the Silver Lake Highway. In addition, a simple mass (water) balance analysis was applied to the Klamath Marsh using inflow, outflow, and stage measurements along with consumptive use estimates from irrigation. Again, the analysis was to investigate the relationships between upstream flows, marsh levels, and downstream flows. Finally, a general comparison of Williamson river hydrographs above and below the marsh was made for a qualitative discussion on the relationship between marsh inflows and outflows.

Analysis:

Klamath Marsh Stage Influence on Williamson River Accretions below the Marsh:

The first part of the analysis investigated the relationship between marsh levels and accretions (springs and groundwater inputs to a river) downstream of the marsh between the Kirk gauging station (11493500) and the Williamson river above the Sprague confluence. The accretions are the difference between discharge at these two locations. Although no gage exists on the Lower Williamson River (LWR) just above the Sprague confluence, a phantom gage record was created by subtracting flow at the Sprague gage (11501000, near Chiloquin) from the flow at the Williamson gage (11502500, below the confluence with the Sprague). A record from 1961-1998 was created which covers the same period as the miscellaneous stage measurements for Klamath Marsh (1961-1980 and 1992-1998).

A plot of marsh stage versus LWR accretions (Figures 1a through 1f) does not support any relationship between marsh levels and downstream accretions. No trends were found for stage and: 1a) concurrent accretion estimates, 1b) 30 day average accretion centered on the stage reading date, 1c) 30 day average accretion after the stage reading date, 1d) 30 day average accretion one month after the reading date, 1e) daily accretion value two months after the reading date, and 1f) 30 day average stage versus 30 day average accretion. These findings are not surprising considering the consistent flow of Spring Creek (the main contributor of accretions in this reach) and the relative slow movement of groundwater in general. There may be longer seasonal or yearly relation between marsh levels and downstream accretions. However, for purposes of water distribution and management, accretions downstream of the Klamath Marsh seem to be independent of marsh water levels. That is downstream flows would not by augmented through increased accretions brought about by increasing Klamath Marsh water levels.



Klamath Marsh Stage vs Williamson Accretion Between K-Marsh and Chiloquin (concurrent daily value)

Figure 1a

Klamath Marsh Stage vs Williamson Accretions Between K-Marsh and Chiloquin (30-day average 1 month after reading)

Figure 1d

Klamath Marsh Stage vs Williamson Accretions Between K-Marsh and Chiloquin (monthly average)

Figure 1b

Klamath Marsh Stage vs Williamson Accretions Between K-Marsh and Chiloquin (60-day

Figure 1e

Klamath Marsh Stage vs Williamson Accretions Between K-Marsh and Chiloquin (30-day average after reading)

Figure 1c

Klamath Marsh 30 day average Stage vs 30-day average Williamson Accretions Between K-Marsh and Chiloquin

Figure 1f

Figure 1: Marsh Stage versus Downstream Accretions

Klamath Marsh Stage Relation to Williamson River Discharge below Klamath Marsh:

Marsh Stage versus Discharge at Kirk:

At least two previous studies have determined that a relationship exists between the water level in Klamath Marsh and Williamson discharge at Kirk (Norvelle et. al., 1981, unpublished USFWS paper). Both studies noted that because of the basalt sill at the outlet of the Klamath Marsh Lowland, there is a marsh stage threshold, below which, flow ceases at the Kirk gauging station (i.e., below the marsh). Norvelle et. al., estimated that streamflow at Kirk falls rapidly to zero when stage in the marsh falls below 4,513 feet (mean sea level, MSL). In a more detailed analysis of this stage discharge relationship, USFWS found that the stage at which flow ceases at Kirks Reef in the summer was between 4012.15' and 4012.82' MSL. The range in stage values corresponding to zero-flow at Kirk was thought to be reflective of different antecedent soil conditions in the marsh. During a dry year, when a higher percentage of the marsh soils are unsaturated, more water in the marsh would flow into seepage and bank storage, requiring a higher stage necessary to maintain flow at Kirk. Likewise, during a wet year, when marsh soils are saturated, less water would flow into bank storage and more of the marsh water would be available for flow at Kirk, requiring a lower stage to maintain flow at Kirk.

Using linear regression for the miscellaneous stage measurements and discharge readings at Kirk taken between 1992-1995, the USFWS study found the marsh Stage could be predicted from flow at Kirk based on equation 1 when discharge at Kirk was non zero.

$$Stage(ft) = .0027 \times KirkFlow(cfs) + 4512.67 \qquad (1)$$

Solving the above equation for the discharge at Kirk gives the predictive relationship between stage levels and flows at Kirk.

$$KirkFlow(cfs) = \frac{Stage(ft) - 4512.67}{.0027} \qquad (2)$$

Based on this equation from the linear regression, if stage in the marsh falls below 4512.67' MSL flow ceases at Kirk.

For this study, the same general approach was used—linear regression of miscellaneous marsh stage versus concurrent non-zero discharge measurements at Kirk. Figure 2 demonstrates that although the y-intercept is slightly different, 4512.80' versus 4512.67', the derived stage discharge relationship agrees with the USFWS study. Marsh stages below this threshold result in zero flows at Kirk.

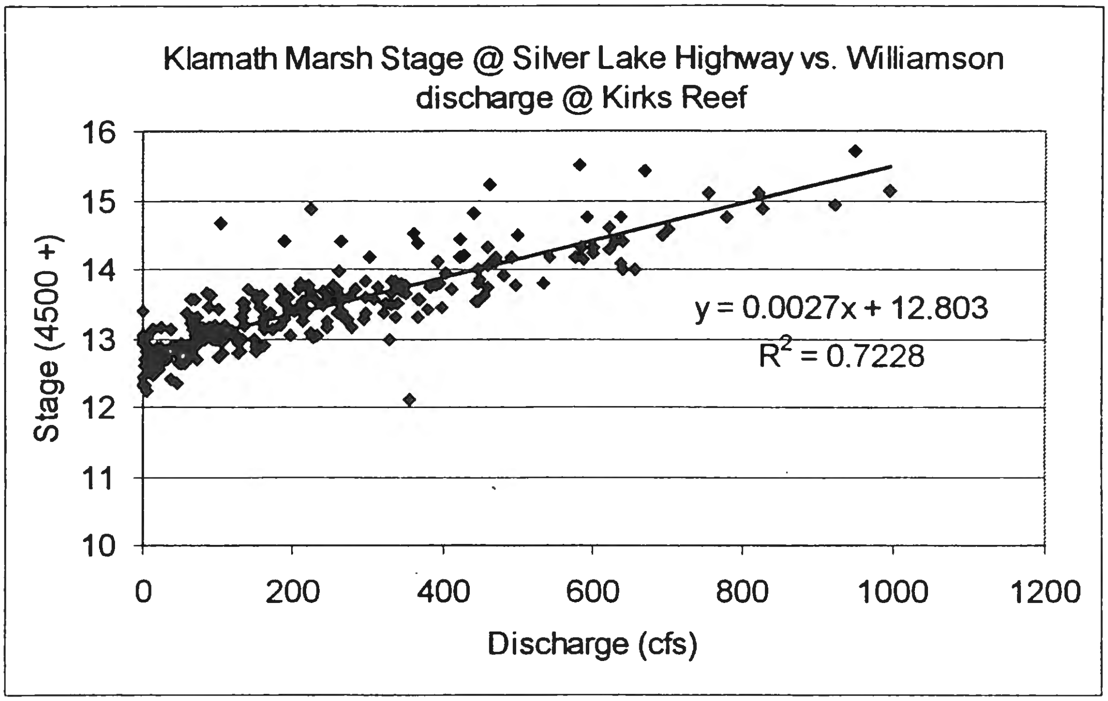


Figure 2: Marsh Stage versus Williamson Discharge at Kirks Reef

Marsh Stage versus Discharge at Williamson above Sprague Confluence:
It has already been shown, that there is no relationship between marsh levels and downstream accretions in the Williamson River. However, a relationship does exist for surface flows at Kirk and marsh stage. It seems probable that this relationship would extend downstream to the confluence with Sprague River.

Figure 3 compares Klamath Marsh stage to Williamson discharge at Chiloquin above the Sprague River confluence. The plot demonstrates that for marsh stages above approximately 4512.5' MSL there is a trend of increasing discharge at Chiloquin for increasing marsh stage. This corresponds to the approximate threshold marsh level for flow at Kirk discussed in the previous section. Below this marsh level, there is no flow at Kirk and no relationship between marsh levels and discharge at Chiloquin as demonstrated by the horizontal trend of the plot below 12.5'. This finding agrees with the accretions/stage analysis. When the discharge at Kirk is zero, flows at Chiloquin are derived solely from accretions, which where not found to be related to marsh stage. Therefore, discharge at Chiloquin should not be related to marsh stage when the discharge is composed of accretions only.

This analysis shows that if the marsh stage is above roughly 4512.80' MSL and if the marsh level could be increased by control of irrigation, some increased flows between Kirk and Chiloquin would occur.

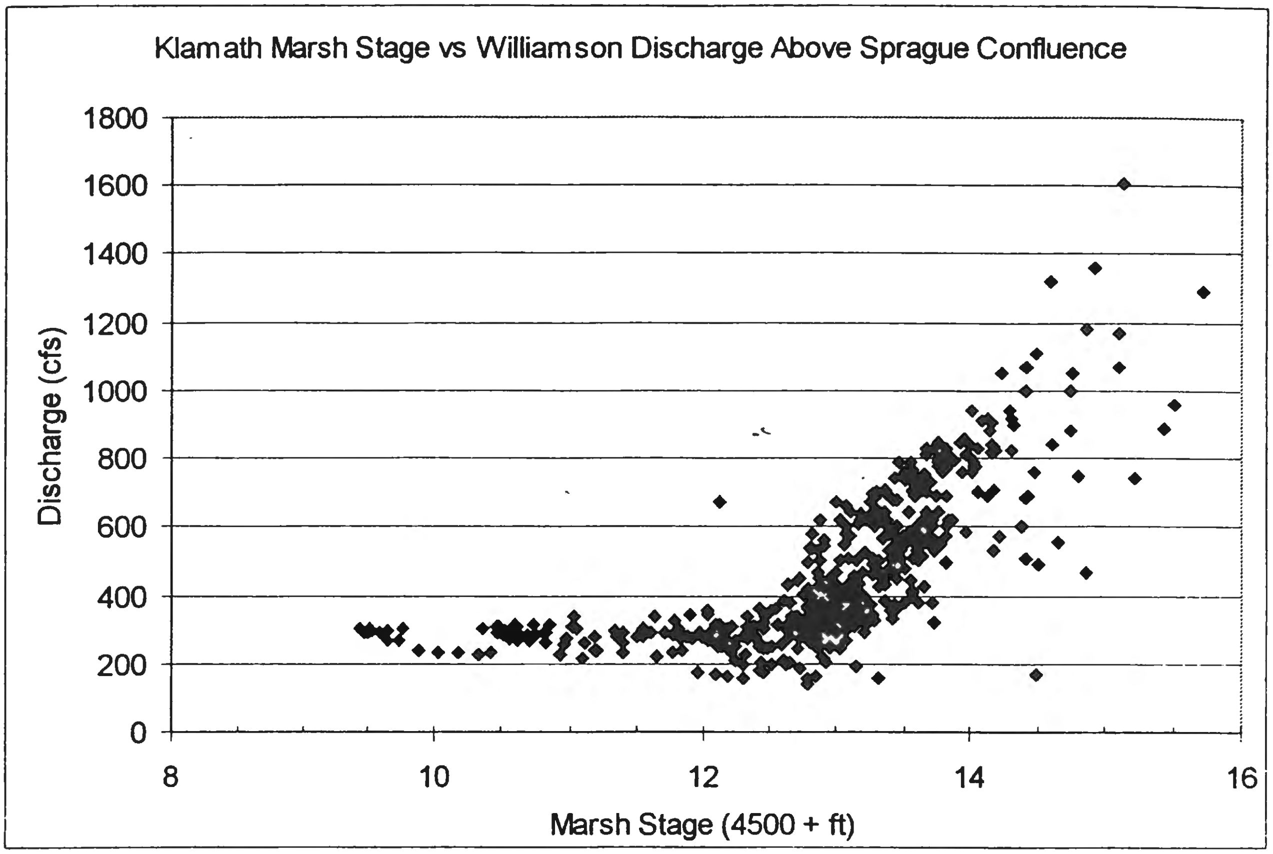


Figure 3: Klamath Marsh Stage vs Williamson Discharge above Sprague Confluence

The Relation of Surface Inflows on Klamath Marsh Water Levels.

Irrigation Effects on Marsh Levels:

The analysis in the previous sections demonstrated that flows downstream of Klamath Marsh are related to the marsh stage if the stage is above the sill of the basalt dam located at the outlet of the Klamath Marsh Lowland. Therefore, if the stage is near this threshold, downstream flows may be increased if the marsh stage can be raised through management of upstream irrigation. The analysis in this section investigates how irrigation from surface inflows into the marsh influences marsh water levels. Specifically the maximum marsh stage increase attainable through shutoff of all upstream irrigation is calculated and compared with historic marsh levels from 1992 to 1997 to see if flows downstream could have been increased.

A mass or water balance approach was employed for this analysis using the entire Klamath Marsh Lowland as the control volume (i.e., study area). The control volume includes the Refuge, irrigated lands to the west of the refuge near Big Spring Creek and Cow Creek, and the Solomon Flats area. All consumptive use affecting surface inflows into the marsh were included in the analysis including diversions within the Refuge. The basic concept is that the monthly change in water stored in the control volume is equal to inflows minus outflows (Equation 3) over a month.

$$\Delta V_{cv} = Q_{in} - Q_{out} \qquad (3)$$

The first term in equation 3 is simply the change in standing water in the marsh plus the change in water stored in the soil matrix or bank storage (Equation 4a, Figure 4a).

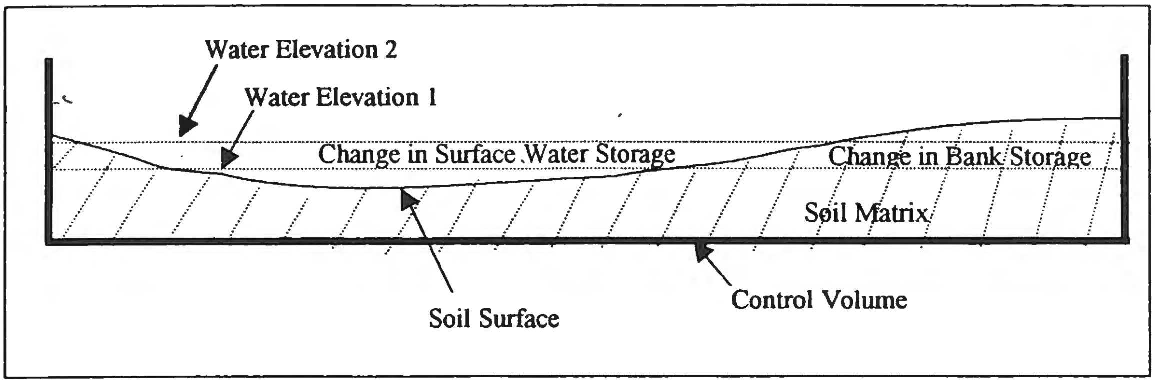


Figure 4a: Schematic for Change in Marsh Water Storage

$$\Delta V_{cv} = \text{Change in Surface Water Storage} + \text{Change in Bank Storage} \qquad (4a)$$

In mathematical terms the change in surface water storage is the average wet area at both stages (water elevations) multiplied by the increase in stage. The bank storage is the average unsaturated area at both stage levels multiplied by the soil porosity and the increase in stage (Equation 4b, Figure 4b).

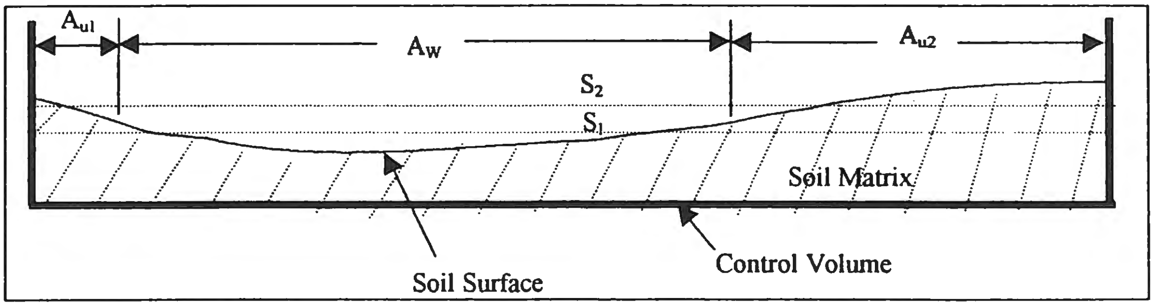


Figure 4b: Mathematical Schematic for Change in Marsh Water Storage

$$\Delta V_{cv} = A_w \times (S_2 - S_1) + \eta \times (A_{u2} + A_{u1}) \times (S_2 - S_1) \qquad (4b)$$

In the preceding equation A_W represent the wet area, A_u represents the unsaturated area, S_2 and S_1 represent the marsh water levels, and η represents soil porosity.

The second term in equation 3 (Q_{in}), inflows, consists of the surface inflows (Q_{si}), precipitation (P), and groundwater inflows (G_{wi}) (Equation 5a).

$$Q_{in} = Q_{si} + P + GW_i \tag{5a}$$

The final term in equation 3 (Q_{out}), outflows, consists of the surface outflows (Q_{so}), evapotranspiration from the Klamath Marsh Lowlands (ET), and groundwater outflows (GW_o) (Equation 5b).

$$Q_{out} = Q_{so} + ET + GW_o \tag{5b}$$

Figure 5 is a schematic of the inflows and outflows terms in the mass balance.

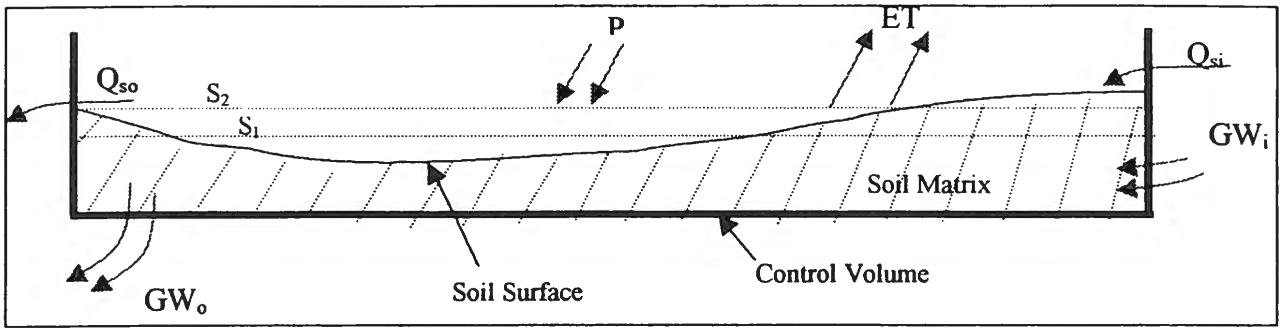


Figure 5: Schematic of Marsh Inflows and Outflows

The final mass balance equations is obtained by substituting equations 5a and 5b into equation 3 to give equation 6:

$$\Delta V_{cv} = (Q_{si} + P + GW_i) - (Q_{so} + ET + GW_o) \tag{6}$$

Thus, the change in water stored in the marsh over a month can be calculated by adding surface water inflows, groundwater inflows, precipitation, and subtracting surface outflows, groundwater outflows, and evapotranspiration.

An important concept in consideration of management of upstream irrigation is the maximum increase in marsh stage attainable from shutoff of irrigation from all marsh surface inflows. If the calculated maximum increase is less than the difference between the stage threshold for flow initiation at Kirk and the historical marsh levels, then no increase in flow would have been realized through management of irrigation. For this analysis, we will examine the historical 1992-1997 marsh stage measurements.

If marsh levels were to increase over what would occur under normal operating conditions (i.e., normal irrigation practices) over a month, the terms in equation six would have to be altered. Clearly there is no means to alter precipitation, groundwater inflow and outflow. Surface flows into and within the marsh can be altered through elimination of diversions. If diversions within the upstream section of the refuge were eliminated, ET in this area would be reduced. However, more water would be delivered to the lower marsh, which would expand thus increasing ET in the lower section. In addition, elevation differences between the upper and lower sections are minute, thus water would seep into the upper refuge at any rate, although perhaps not to the extent as with the present diversions. Any increase in the supply of surface water to the marsh through a no-irrigation practice would increase soil moisture within the marsh and thus increase marsh ET. The net result under no diversions/irrigation above or within the marsh would probably be an increase in marsh ET. However, to estimate the maximum possible increase in marsh stage, the conservative assumption will be made that ET remains constant within the Klamath Marsh for any change in stage. Integrating this information into equation 6, the increase in stage brought about by a no-irrigation policy becomes.

$$\Delta V_{noirr} = \Delta Q_{si} - \Delta Q_{so} \qquad (7)$$

Thus, any additional change of stored water in the marsh over historic conditions could only occur through changes in surface inflows or outflows. Incorporating equation 7 into equation 4b results in the following to calculate the maximum change in stage

$$A_w \times (S_2 - S_1) + \eta \times (A_{u2} + A_{u1}) \times (S_2 - S_1) = \Delta Q_{si} - \Delta Q_{so} \qquad (8a)$$

Combining the area terms gives:

$$A_{weff} \times (S_2 - S_1) = \Delta Q_{si} - \Delta Q_{so} \qquad (8b)$$

where A_{weff} is the effective wet area and S_2-S_1 is the maximum change in stage or ΔS. If the marsh stage rises above 4512.80' MSL, surface outflow will just begin at Kirks reef. Setting the target stage (S_2) to this elevation will allow the calculation of the lowest marsh level (S_1) from which the marsh could be raised to start to increase flow below Kirk within a given month. The change in outflow ΔQ_{so} associated with this change in stage is essentially zero, since flows near the threshold stage (4512.80' MSL) will be near zero and flows associated with lower stage (< 4512.80' MSL) will be zero. Therefore, the final equation to calculate the maximum change in storage is:

$$A_{weff} \times (S_2 - S_1) = \Delta Q_{si} \qquad (9a)$$

or

$$S_2 - S_1 = \frac{\Delta Q_{si}}{A_{weff}} \tag{9b}$$

where ΔQ_{si} , change in surface inflows, is the consumptive use from irrigation on the tributaries to Klamath Marsh. For the month of May, this corresponds to roughly 125 cfs (7700 ac-ft), based on 10,000 acres of pasture irrigated from tributaries to Klamath Marsh. Using an area-elevation curve (Figure 6) for saturated area derived from areal photographs and augmented with topographic information, the saturated area for the entire 60,000 acres Klamath Marsh Lowlands corresponding to the threshold stage of 4512.67 is approximately 20,000 acres.

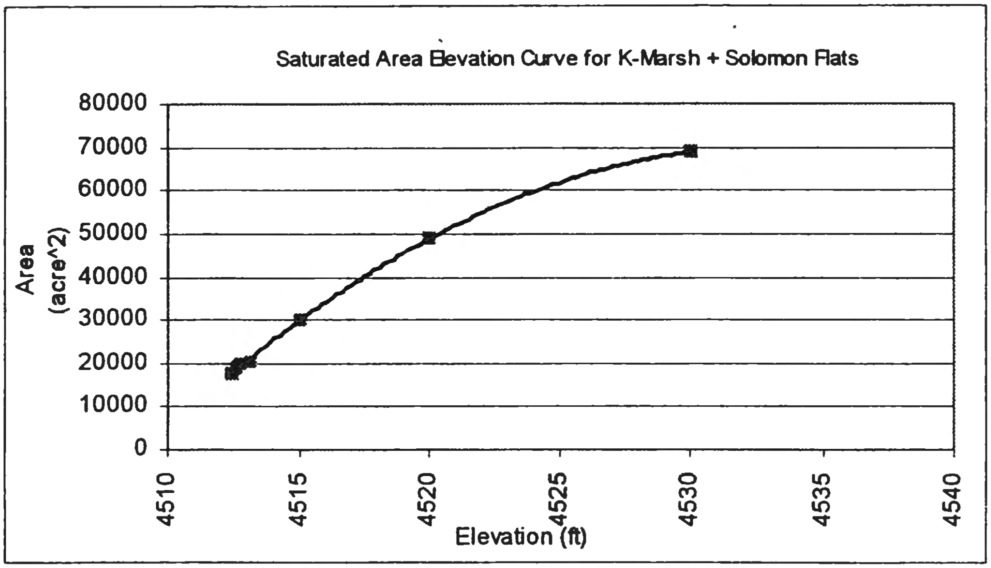


Figure 6: Area Elevation Curve for Klamath Marsh Lowland

Therefore, the unsaturated area (i.e., area where the water table is not at the surface) would be 40,000 acres for the Klamath Marsh Lowlands. However, for bank storage calculations, water would probably not have time to seep into the entire 40,000 acres from the saturated area (standing water area) in a month. Therefore, the unsaturated area was defined using the immediate boundaries of the marsh, resulting in a value of 18,000 acres for bank storage (35,000 total acres in marsh – 17,000 saturated marsh acres = 18,000 unsaturated acres). Using a soil porosity of 0.45 multiplied by the bank storage acres and then adding the saturated acres (0.45 x 18,000 + 20,000) gives a final effective water area of roughly 28,000 acres.

Substituting the effective water area and consumptive use numbers into equation 9b gives the maximum change in marsh stage for the month of May as 0.28 feet. In other words, if the marsh level were below 0.28 feet (i.e., 4512.52' MSL) of the basalt sill at Kirk, no flow would occur downstream from no-irrigation on all surface tributaries to Klamath

Marsh. It should be noted that if ET did increase with increased surface inflows, the maximum change in marsh stage would be reduced.

Using the same approach and consumptive use numbers for the remaining months the minimum marsh level for passing upstream flows to downstream users was calculated (Table 1). Table 2 demonstrates that for most summer months in the period of 1992-1997, marsh levels were too low (shown in gray) to increase the stage above the basalt sill at Kirks Reef through control of upstream irrigation.

Table 1: Minimum Marsh Control Levels and Maximum Possible Change in Stage

Month	CU from Tributaries (cfs)	CU (ac-ft)	Stage 2 (ft)	Surface Storage Area (ac)	Bank Storage Area * Porosity	Total Effective Wet Area (ac)	Calculated Stage 1(ft)	Max Change in Stage (S2-S1) (ft)
April	47	2795	4512.80	19854.0	7941	27795	4512.70	0.10
May	125	7673	4512.80	19854.0	7941	27795	4512.52	0.28
June	107	6362	4512.80	19854.0	7941	27795	4512.57	0.23
July	30	1835	4512.80	19854.0	7941	27795	4512.73	0.07
Aug	15	902	4512.80	19854.0	7941	27795	4512.77	0.03
Sept	16	933	4512.80	19854.0	7941	27795	4512.77	0.03
Oct	9	540	4512.80	19854.0	7941	27795	4512.78	0.02

Table 2: Historical Marsh Levels for WY 1992-1997

	1992	*1993*	*1994*	*1995*	*1996*	*1997*
April	4512.86	4514.00	4512.79	4513.00	4512.86	4513.07
May	4512.72	4513.13	4512.65	4513.00	4512.90	4512.92
June	4512.14	4513.00	4512.24	4512.68	4512.67	4512.92
July	4511.85	4512.14	4511.19	4512.30	4512.30	4512.60
Aug	4511.89	4511.89	4510.70	4511.36	4511.50	4511.88
Sept	4510.75	4511.54	4509.88	4510.70	4510.70	4512.24
Oct	4510.53	4511.40	4509.47	4510.40	4510.48	4512.65

This analysis demonstrates that the immense storage capacity of Klamath Marsh would reduce much if not all of the benefit derived from eliminating upstream consumptive use. Furthermore, the conservative assumption of constant ET (an assumption that favors higher estimates of maximum stage change) along with typical summer marsh levels associated with dry years (< 4512 MSL), make it unlikely that control of upstream irrigation would benefit downstream flows in a reasonable time frame.

Williamson Discharge above Klamath Marsh Relation to Klamath Marsh Stage:

In the previous section, it was shown that increased flows brought about by eliminating irrigation in the tributaries to Klamath Marsh would probably not result in higher flows downstream of the marsh. Further evidence for this hypothesis is found when examining UWR discharge and miscellaneous marsh stage measurements. Figure 7 compares stage at Klamath Marsh to the discharge at Rocky Ford. A strong correlation between flows and marsh levels was not found for marsh stage measurements and 7a) concurrent flow measurements, 7b) flow 4-days prior to the stage measurement, 7c) flow 10-days prior to the stage measurement, 7d) monthly average flow prior to the stage measurement. These results give credence to results in the previous section that marsh levels aren't very responsive to changes in surface inflows. The results are also supported by previous studies estimate of annual groundwater inflow to the marsh (430,000 ac-ft) compared to the annual inflow from the Williamson (66,000 ac-ft, or 15% of groundwater).

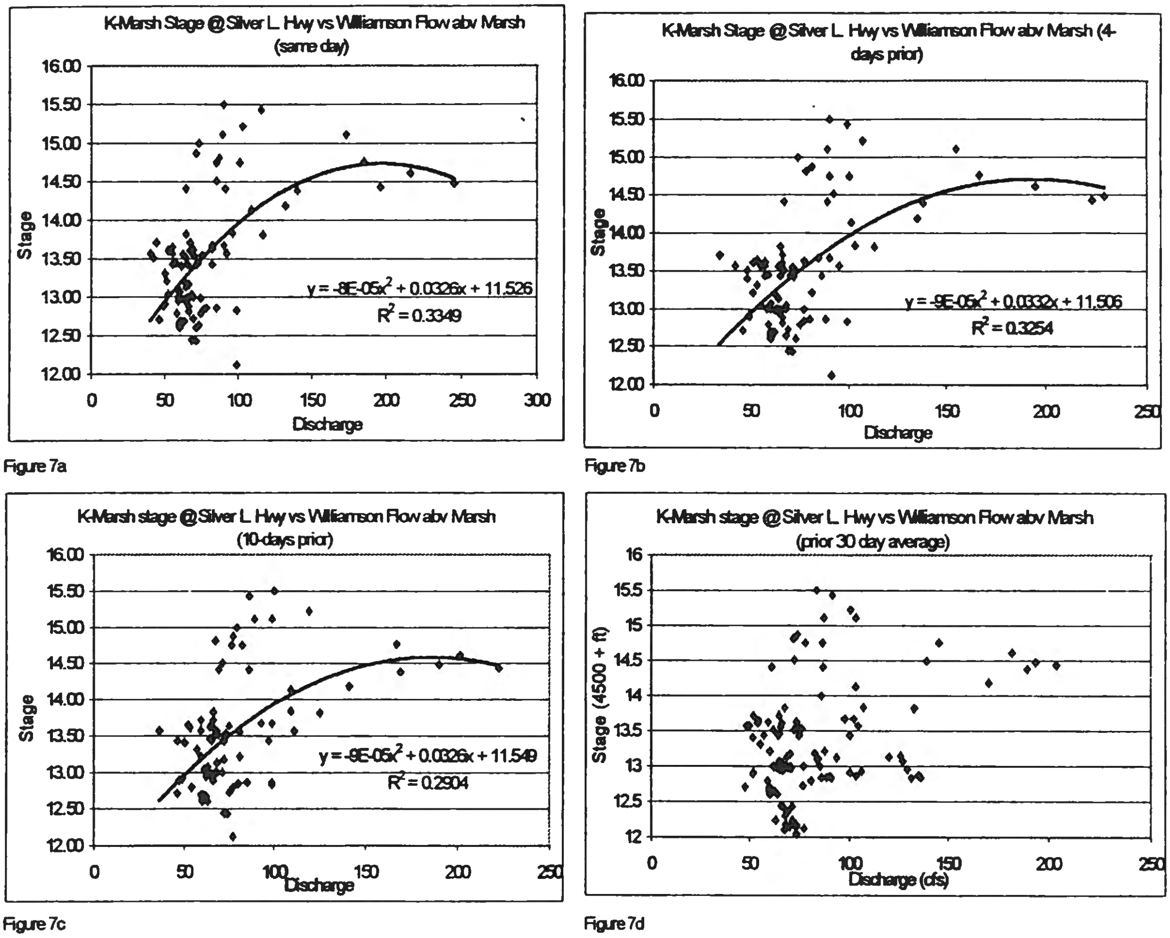


Figure 7a

Figure 7b

Figure 7c

Figure 7d

Figure 7: Klamath Marsh Stage vs Williamson Flow at Rocky Ford (above Marsh)

<u>The Relation between Discharge Above and Below Klamath Marsh:</u>

A comparison of UWR (at Rocky Ford) and LWR (at Kirks Reef) hydrographs gives a general overview on the relationship of marsh inflows to outflows. As demonstrated in figures 8 and 9 there is not a clear correlation between peak flows above and below the marsh. The peak flow at Rocky Ford actually comes after the peak flow at Kirk below the marsh in WY 1974. In water years 1976 and 1977 no peak flow above the marsh is present, yet flows below the marsh still show a spring runoff peak. The magnitude of the flows is quite different between the two locations; with LWR Spring flows five times that of UWR discharge. Given the lack of other significant surface tributaries, a good portion of this runoff must be coming from groundwater. Another interesting point is that although flow in the Williamson above the marsh is relatively constant, discharge below the marsh is highly variable. Flows below the marsh were near zero in water years 1974 and 1976 even after peak flows of 850 and 570 cfs, respectively. Plotting a regression line against concurrent monthly average flow at both locations gives a fair R^2 value of 0.6123. However, the residual plot is heteroscadastic, indicating a poor regression fit. Furthermore, any relationship between inflows and outflows is probably more indicative of response by the stream at both locations to basin wide conditions, as opposed to a causal relationship between inflows and outflows.

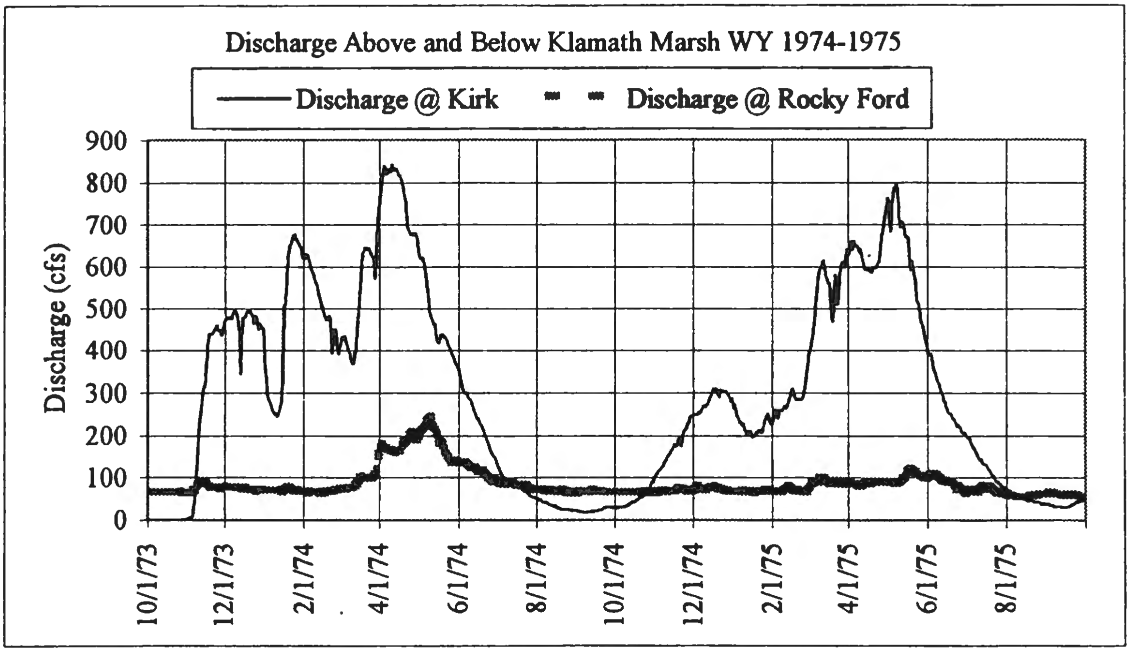


Figure 8: Williamson Hydrographs for Water Year 1973 and 1974 above and below Klamath Marsh

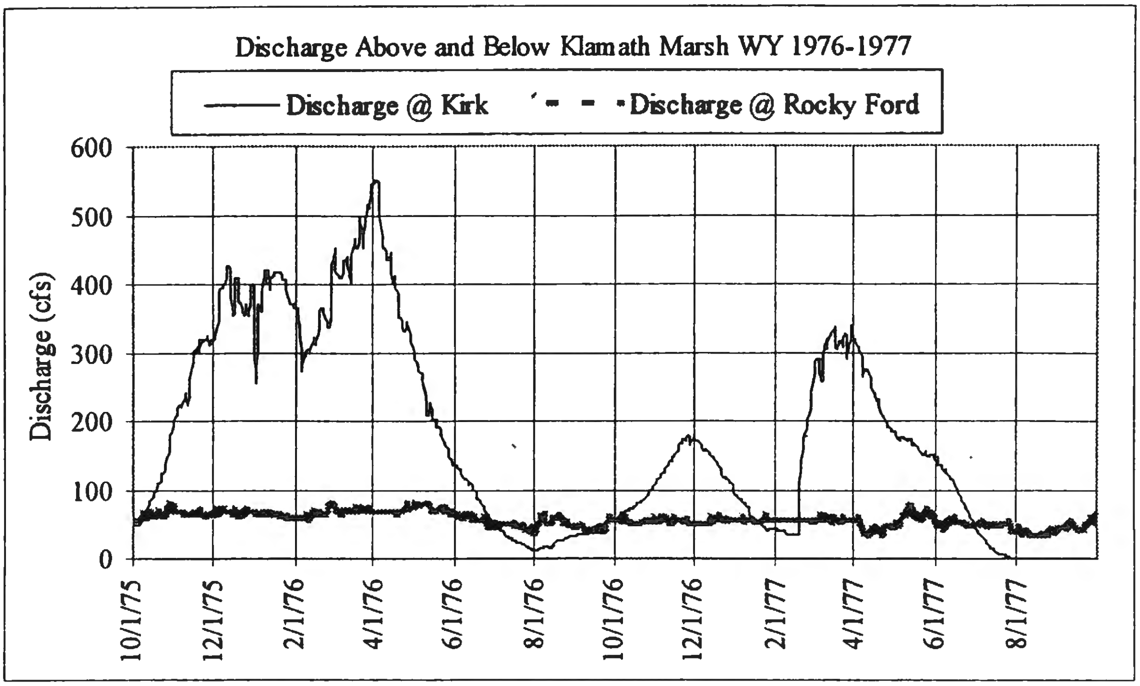


Figure 9: Williamson Hydrographs for Water Year 1976 and 1977 above and below Klamath Marsh

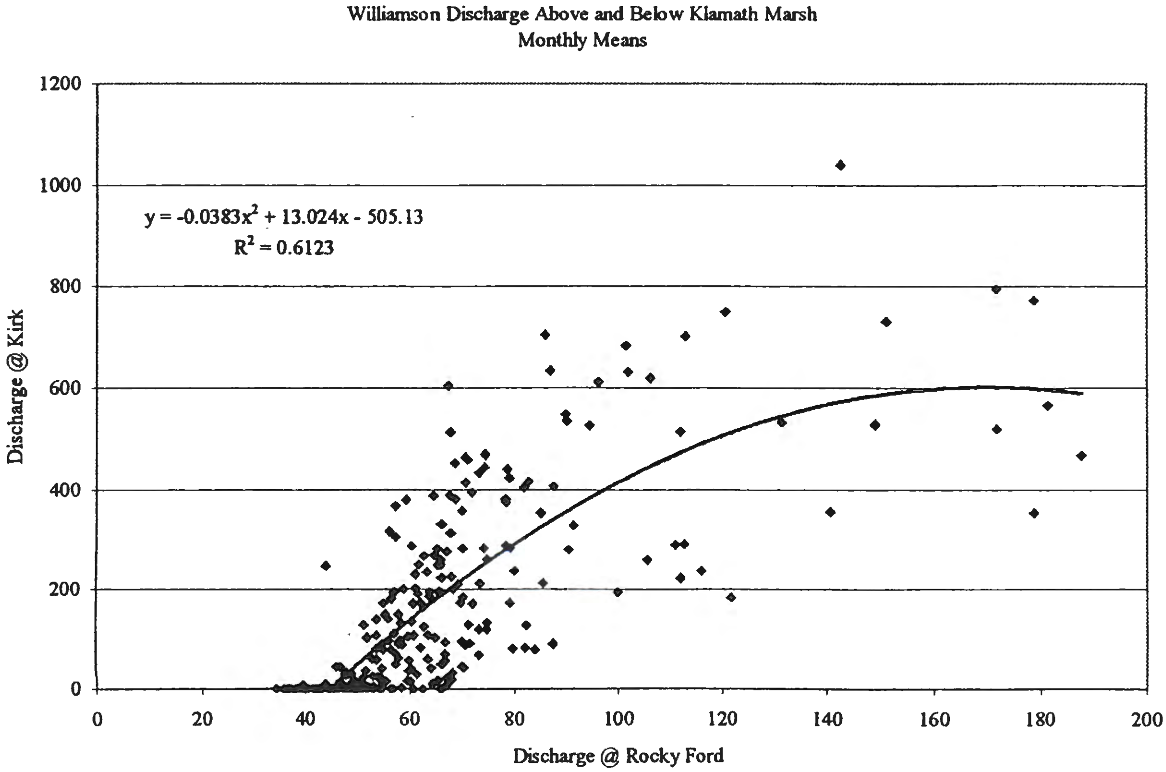


Figure 10: Williamson Discharge Relation Above and Below Klamath Marsh

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