U.S. Fish & Wildlife Service

Evaluation of Water Monitoring Program at Ruby Lake National Wildlife Refuge

Report Author: Rachel Esralew, Hydrologist, U.S. Fish and Wildlife Service Pacific Southwest Region Inventory and Monitoring Initiative

Field Team: Rachel Esralew, Sheila Strachan, Joshua Prososki, Rod Wittenberg

Report Date: April 11th, 2014

U.S. Department of the Interior

U.S. Fish and Wildlife Service

Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, "North American Vertical Datum of 1988 (NAVD 88)."

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, "North American Datum of 1983 (NAD 83)."

Altitude, as used in this report, refers to distance above the vertical datum.

Evaluation of Water Monitoring Program at Ruby Lake National Wildlife Refuge

Executive Summary

The water supply to Ruby Lake National Wildlife Refuge is fed primarily by numerous springs, most of which flow to the Refuge from the west and the south. Refuge staff has periodically measured and estimated spring flow contributions to the Refuge collection ditch, which re-directs water from springs to wetland management units from 1998 to 2009. Refuge staff wishes to resume monitoring in 2013, but seek to improve the accuracy of measurements if possible given limited time available for monitoring. The purpose of this report was to document an assessment to determine if actions are needed to improve the accuracy and consistency of the existing flow monitoring network. This assessment included a summary of results used to recommend the minimum days required between measurements to properly interpolate between flow measurements, and to recommend any changes to flow calculation procedures to improve calculation accuracy.

A previous analysis of biweekly records and instantaneous records from 1998 to 2011 indicated that much of the spring response is captured between March and October. A measurement frequency to 1 month did not have a substantial impact on total annual flow from the collection ditch to wetland management units, but did substantially impact the net inflow to some units. A 2-week measurement schedule appears to capture spring peak flow better than a 1 to 2 month sampling interval. To maintain consistency with previous datasets, to accurately estimate inflow to some units, and to adequately be able to identify and measure peak inflow to all units, spring inflow to all units (at that receive water directly from the collection ditch) should be collected no less frequently than every 2 weeks between March 1st and August 30th.

In the previous spreadsheets, flow was calculated between visit dates by assuming that the flow was constant between the next visit date and every day just after the day of the last measurement (referred to as “block-type”). An alternative to this calculation would be to conduct a linear interpolation between measurements (referred to as “linear-type”). In order to test whether the block-type or linear-type interpolation method was more accurate for estimate flow between site visits after a board was

pulled, we conducted an experiment where we manipulated boards at 4 selected locations and measured flow immediately after board removal for several days.

Results from the board pulling experiment were not conclusive because results varied between sites. Stabilization of flow after removal of weir boards took about 2 days for one site, but the remaining 3 stations took longer to stabilize, in which flows did not generally stabilize until 3 days after the boards were pulled. A short stabilization time resulted in the block-type method being a better estimator of flow than the linear-type interpolation, whereas a longer stabilization time resulted in the linear-type interpolation being a better estimator of flow. If greater accuracy in inflow or total flow estimation is desired, then a frequency of measurement that is greater than 2 weeks should be used for sites in which boards are manipulated. This recommendation is a lower priority if only end-of-year estimates for spring flow to all wetland units from the collection ditch are sought; in this case, a 1 month to 6 week measurement frequency is likely adequate year-round.

If a more accurate method is desired for future measurements, a new water monitoring spreadsheet should be designed that allows for linear-type interpolation. However, further investigation is needed at additional sites and for a longer period of time to determine if the linear-type method is generally more accurate overall.

Introduction

Water supply to Ruby Lake National Wildlife Refuge is fed primarily by numerous springs, most of which flow to the Refuge from the west and the south. As a result of a spring synoptic (near-simultaneous measurement of spring discharge at multiple locations) in May of 2012 to supplement a previous spring synoptic in 1984, a total of 216 springs were estimated to supply water to the Refuge (Esralew and Holmes, 2012). Additional sub-aqueous springs supply water to the Refuge but could not be measured (Esralew and Holmes, 2012).

Refuge staff has periodically measured and estimated spring flow contributions to the Refuge collection ditch, which re-directs water to habitat management units, from 1998 to 2009 (Esralew and others, 2013, figures 1 and 3). Methods for these stations include measurement of water height at a weir (water control structure stop board) and use of a weir equation which assumes a static value for velocity head. Measurements were made approximately bi-weekly. Discharge values were interpolated between dates and summed to estimate total annual contributions by assuming a constant rate discharge from the last date of measurement to the day after the previous measurement (Rod Wittenberg, RLNWR Assistant Refuge Manager, U.S. Fish and Wildlife Service, written communication, April 2011).

The bi-weekly monitoring program for monitoring inflow and outflow of wetland management units conducted during 1998–2009 is sufficiently long-term to start to understand annual variability in spring flow supply. However, the accuracy of these estimates may be poor because of the following:

- temporal resolution and assumptions regarding interpolation (static flows are assumed between measurement days where boards are manipulated)
- potential inaccuracies in discharge calculation because a weir equation employs a static default for velocity head and does not contain a correction for submergence[1]
- challenges in ease of use of the Microsoft Excel spreadsheet used to calculate annual water budget (R. Wittenberg, assistant refuge manager, U.S. Fish and Wildlife Service; written communication; December 2012)

The following suggestions to improve the existing periodic flow monitoring network were recommended in the Water Resources Inventory and Assessment (Esralew and others, 2013) to support the Service in continuation of periodic flow monitoring in the northern springs and managed wetland area:

- conduct an assessment to determine the minimum days required between measurements to properly interpolate between flow measurements
- improve the Microsoft Excel spreadsheet to reduce the probability of data entry errors and facilitate ease of use
- develop a monitoring program that uses the Cal Poly Weir Stick (Irrigation Training and Research Center, 2003) to obtain better estimates of discharge[2] and stop board risers (weirs), but compare these measurements with the previously used methods
- The purpose of this document is to summarize results from an assessment used to recommend the minimum days required between measurements to properly interpolate between flow measurements. An improved Microsoft Excel spreadsheet was also development to reduce the probability of data entry errors and facilitate examination of data once collected in the field.

[1] Submergence results from water that is not free-flowing past the weir, resulting in an elevated water height affected by the downstream water level (or control). Submergence without a correction factor will result in an over-estimation of discharge.
[2] The Cal Poly Weir Stick is designed to take into account velocity head, and a correction factor is available for computing discharge under a submerged weir.

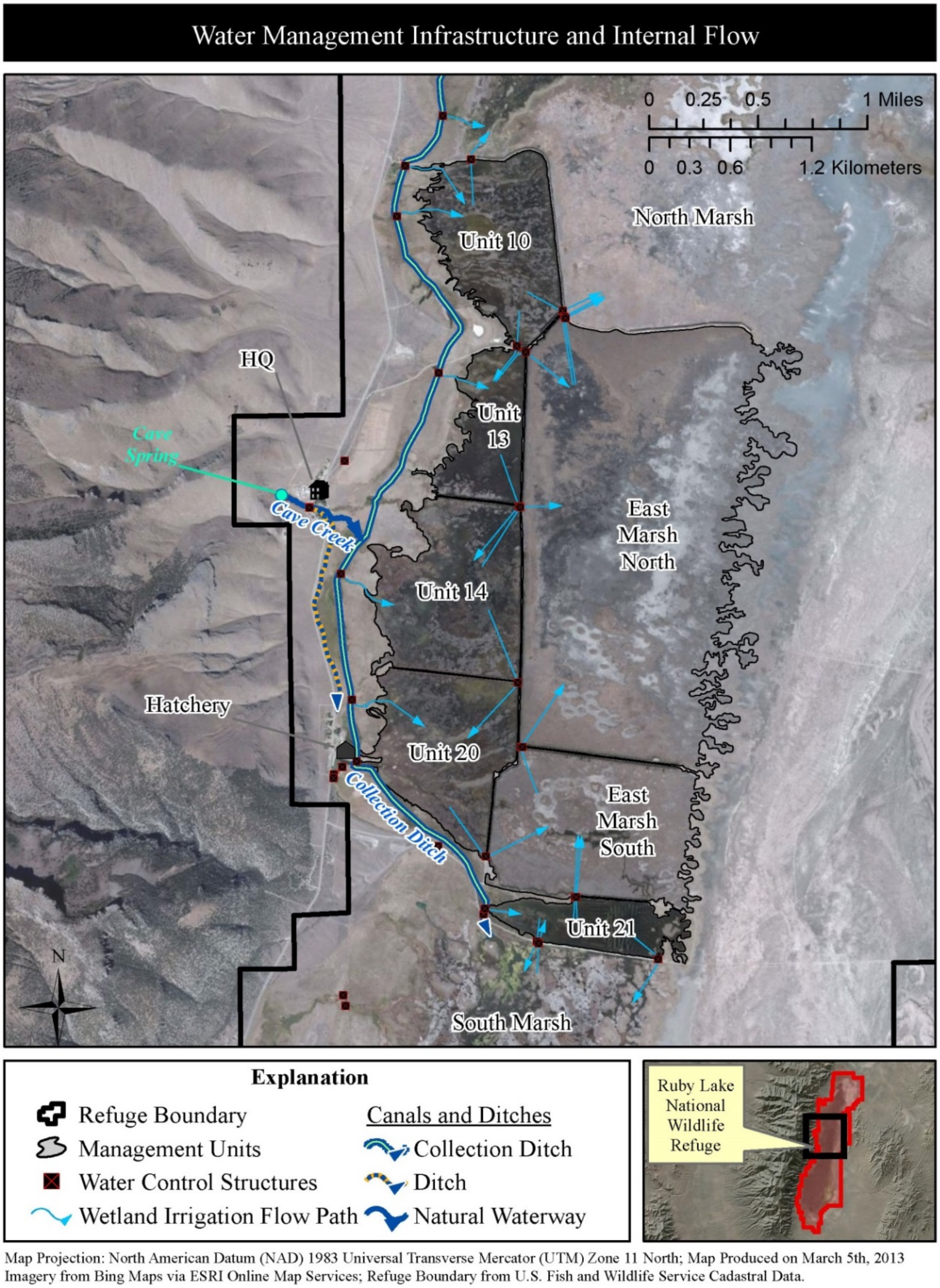


Figure 1. Water management conceptual map and locations of water control structures for Ruby Lake National Wildlife Refuge

Ruby Lake Flow and Elevation Monitoring Locations

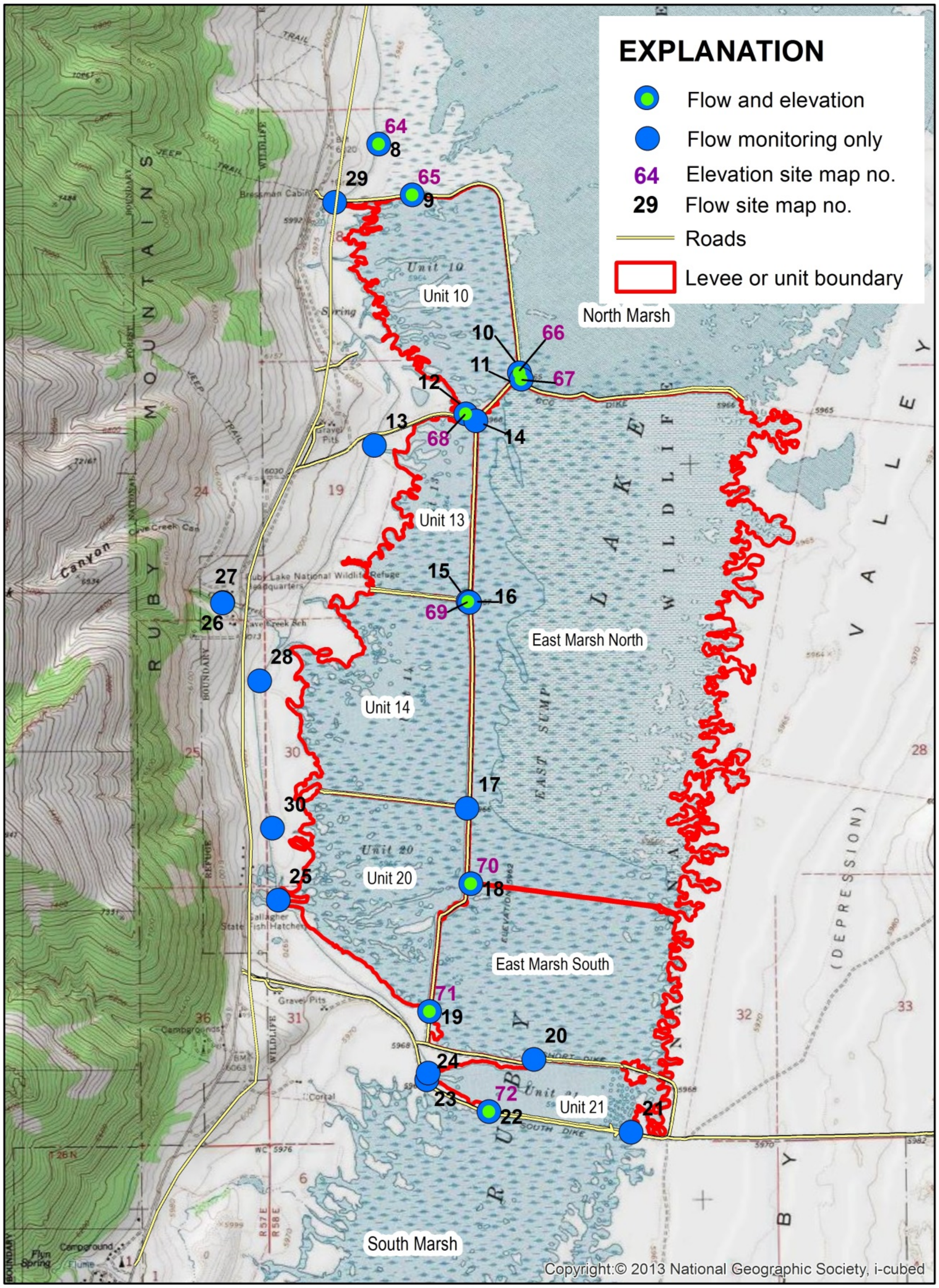


Figure 2. Instantaneous flow and water level monitoring stations at Ruby Lake National Wildlife Refuge

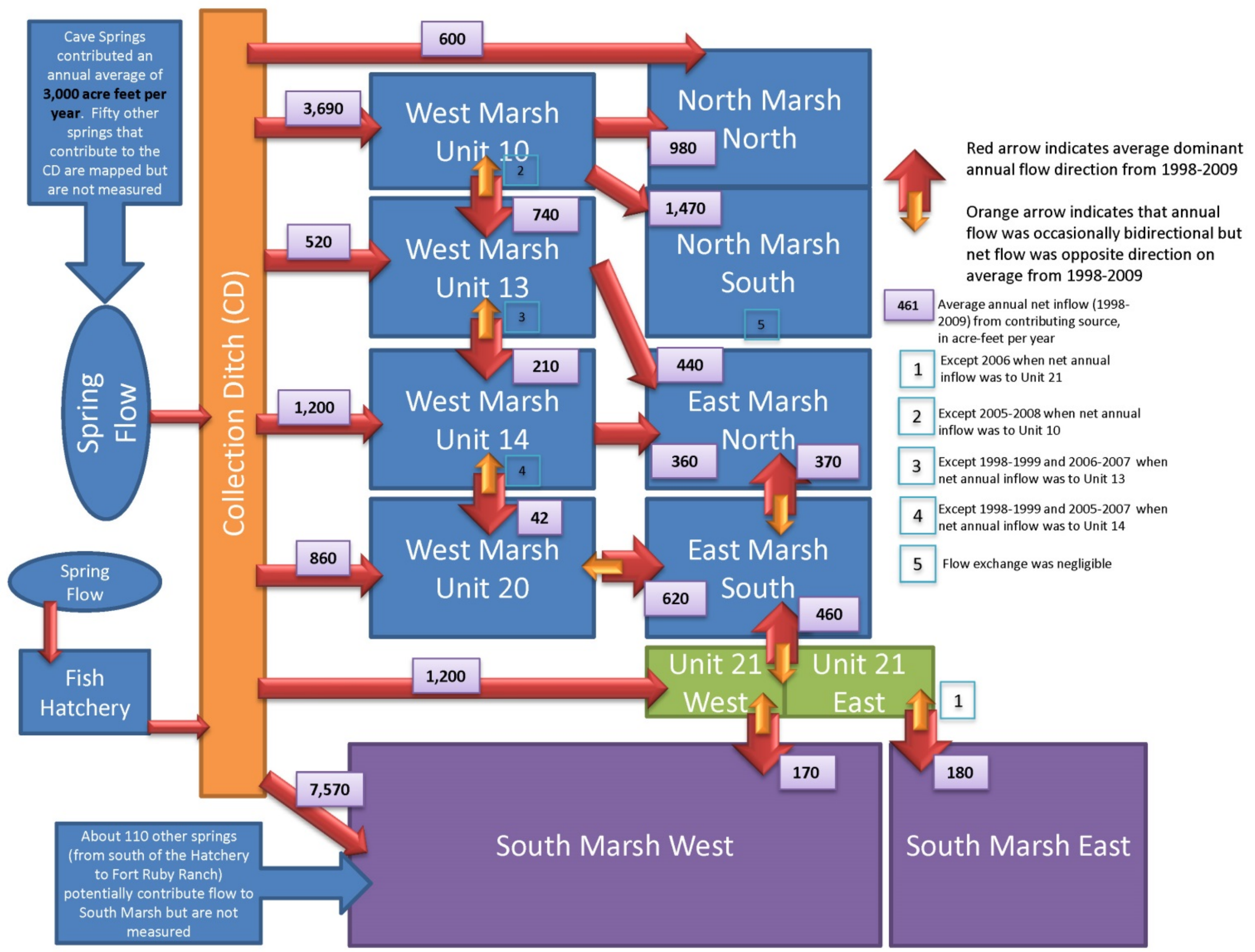


Figure 3. Conceptual schematic of water management system and mean annual net inflow and outflow to wetland management units at Ruby Lake National Wildlife Refuge (size of units are not depicted to scale)

Methods

Process Used to Determine a Minimum Recommended Sample Frequency

A revised water management spreadsheet was developed to store discrete measurements of water level and flow at 23 monitoring stations (stations in which flow measurements are made are listed in table 1 and all stations are shown in figure 2). Data were entered for the calendar year 2009, which is an entire year of measurements at all stations on approximately a 2-week sampling frequency. Data that were collected for the 2009 sheet used a water height measurement and a weir equation (Esralew and others, 2013).

Table 1. Weir measurement locations at Ruby Lake National Wildlife Refuge

Name	Map ID	Does this site receive water directly from the collection ditch?	Was this site measured for board-pulling experiment?
Cave Creek Diversion to Irrigation Canals	82	No	No
Cave Creek Weir	83	No	No
Collection Ditch at Hatchery	81	No	No
Collection Ditch to North Marsh	64	Yes	No
Collection Ditch to South Marsh West	79	Yes	No
Collection Ditch to Unit 10	85	Yes	No
Collection Ditch to Unit 13	69	Yes	No
Collection Ditch to Unit 14	84	Yes	Yes
Collection Ditch to Unit 20	86	Yes	Yes
Collection Ditch to Unit 21	80	Yes	No
East Marsh South to East Marsh North	74	No	No
East Marsh to North Marsh	67	No	No
Unit 10 North to North Marsh	65	No	Yes
Unit 10 South to North Marsh	66	No	No
Unit 10 to Unit 13	68	No	No
Unit 13 to East Marsh North	70	No	No
Unit 13 to Unit 14	71	No	No
Unit 14 to East Marsh North	72	No	No
Unit 14 to Unit 20	73	No	No
Unit 20 to East Marsh South	75	No	No
Unit 21 to East Marsh South	76	No	Yes
Unit 21 to South Marsh East	77	No	No
Unit 21 to South Marsh West	78	No	No

Measurements had been collected but back-logged since 2009 to the current date. Due to staff time limitation, the frequency of measurements was reduced from 2 weeks to about 1-2 months in 2013. In addition, the staff began using a Cal Poly Weir stick (Irrigation Training and Research Center, 2003), which offers improvement in the accuracy of flow measurements.

In order to determine an optimal sampling frequency, we compared calculated flows between 2009 and 2013. We compared results of flow calculations during peak inundation and other times of year by visually interpreting hydrographs between 2009 and 2013. We also compared 2009 with a 2-week sample frequency and 2009 with a 1 month sample frequency using the same analysis procedure described above. For this, measurement dates were systematically eliminated for every other week to produce a dataset with one measurement every 4 weeks (referred to as the “resampled data”). We resampled twice with a different offset by filtering once at the beginning of the month (referred to as “resample 1”), and once in the middle of the month (referred to as “resample 2”). We calculated the annual end-of-year flow estimate for the resampled data and compared this to the original 2009 dataset.

Experiment to determine a recommended flow interpolation method and sample frequency

In the previous spreadsheets, flow was calculated between visit dates by assuming that the flow was constant between the next visit date and every day just after the day of the last measurement. For example, if flow was measured on 1/15/2009 and flow was measured again on 1/30/2009, the flow value on 1/30/2009 was assumed for every day from 1/16-1/30/2009. This “block-type” calculation may overestimate or underestimate flow depending on the change in flow between visit dates, or if water has crested the weir between visits.

An alternative to this calculation would be to conduct a linear interpolation between measurements (referred to as “linear-type”). For example, if the flow measured on 1/15/2009 was 1 cfs and the flow on 1/30/2009 was 15 cfs, then the interpolated flow for 1/16/2009 would be 2 cfs, 1/17/2009 would be 3 cfs, and 1/20/2009 would be 14 cfs respectively. For an annual or seasonal total flow summary, a daily flow with an interpolated value would be summed for every day of the year or season, respectively. This linear-type interpolation may not accurately estimate flows when water has ceased to flow or water has crested the weir during site visits. However, there is no other more simple or feasible alternative to calculation of flow between measurement dates when this occurs, simply than to increase measurement frequency.

In order to test whether the block-type or linear-type interpolation method was more accurate for estimate flow between site visits after a board was pulled, we conducted an experiment where we manipulated boards at 4 selected locations and measured flow immediately after board removal for several days. We increased the frequency of measurement from every 4 hours to every day for a period of 4 days. This allowed us to estimate an actual daily flow. We were then able to compare the ability of the block-type and linear-type interpolation to accurately estimate total flow between the first and last measurement date (during the experiment period) to a more accurately and frequently-computed total flow.

We also used the results from this experiment to estimate stabilization time after boards are pulled. If flows take a long time to stabilize, both the block-type and linear-type interpolation will probably perform poorly without further modification to the flow calculation procedure. If flows stabilize quickly, then the flow calculation error introduced by both the block-type and linear-type interpolation methods will be reduced.

We initially measured flow and elevation at all measurement locations on 6/11/2013 at around 9:00am. We then pulled boards at sites 65 (Unit 10 North to North Marsh), 76 (Unit 21 to East Marsh South), 84 (Collection Ditch to Unit 14), and 86 (Collection Ditch to Unit 20). We measured flow immediately afterwards and then again at 2:00pm the same day. We made subsequent flow measurements on 6/12/2013 at 8:00am and 2:00pm, 6/13/2013 at 9:00am, 6/14/2013 at 7:30am. We then measured flow again on 6/18/2013.

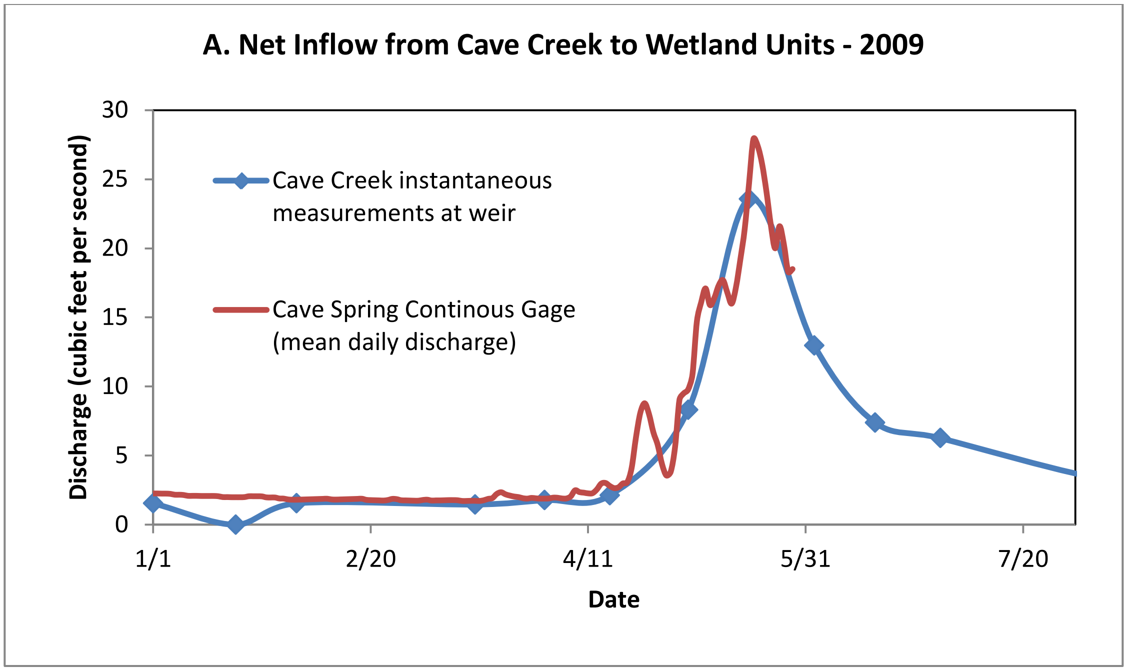
The total flow between 6/11/2013 and 6/18/2013 was computed using both the block-type and linear-type interpolation. Total flow between these two dates was computed both while ignoring all of the measurements in between, and by including all of the measurements in between.

We didn't test a scenario where a weir was flowing and then became dry at a later date. In these cases, without measuring every day, it is difficult to know at what date the weir went dry. In cases where a weir went from not flowing to flowing between measurement dates, the block interpolation method will likely overestimate flow. In cases where a weir went from flowing to not flowing, the block interpolation method will likely underestimate flow. It is assumed that the linear interpolation method would offer no greater benefit to these biases than the block interpolation method.

Results

Minimum Measurement Frequency

The 2013 dataset did not allow us to accurately compute end-of-year estimates because the measurement frequency of 1-2 months was insufficient and because we did not have records available through the end of the year. However, even for selected time periods in which data was collected, the sampling frequency was incomplete or too infrequent to summarize total flows.



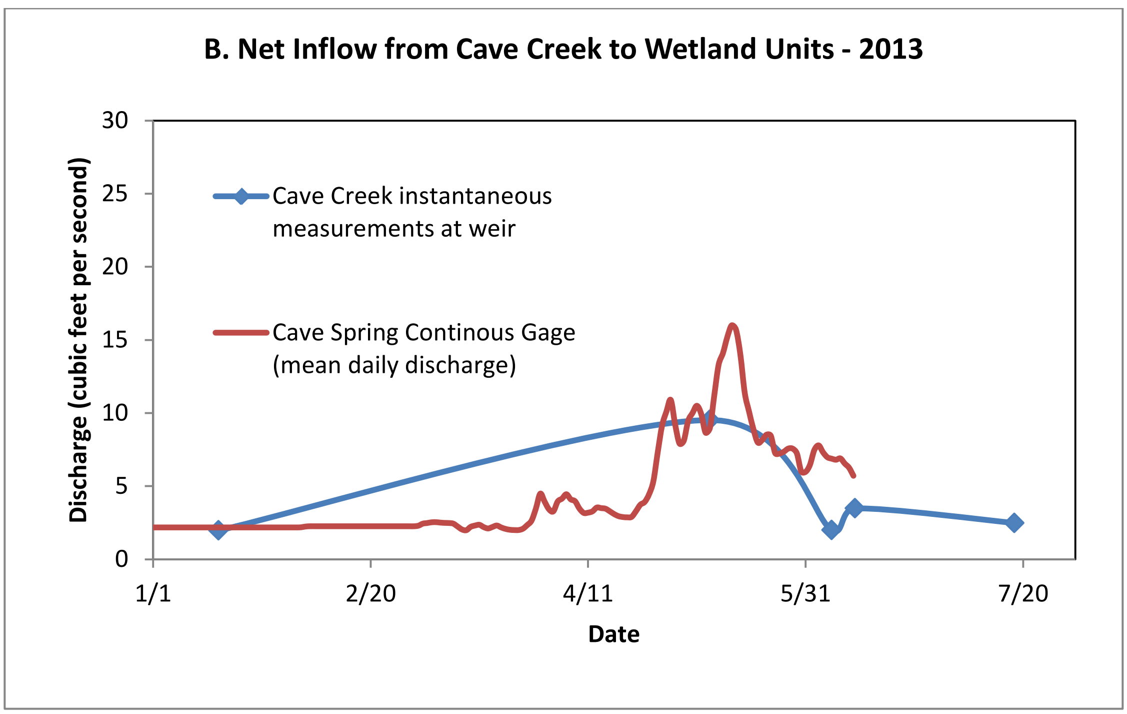


Figure 4. Comparison of mean daily discharge at Cave Spring Channel below Refuge Headquarters (U.S. Fish and Wildlife Service station 457002) to A.) bi-weekly measurements at Cave Creek Weir in 2009 and B.) measurements made every 1 to 4 months at Cave Creek Weir in 2013

In contrast, in the 2009 dataset, a majority of the inflow was observed to come in from late March through late July, with an estimated peak of mid-May to early June (Esralew and others, 2013).

The Cave Spring gage, which measures flow every half hour and was averaged daily, was presented with the instantaneous measurements to compare how well those measurements captured peak daily spring flow during the peak flow season. A 2-week measurement schedule appears to capture these peaks much better (figure 4). Note that the Cave Creek Weir was measured once in 4 months during the start of the year in 2013 (figure 4). Also note that the total net inflow from springs to marsh units can only be calculated when all of the inflows from the collection ditch to other units are measured, which was not always the case in the 2013 dataset.

Furthermore, an analysis of biweekly records and instantaneous records from 1998 to 2011 indicated that much of the spring response is captured between March and October (Esralew and others, 2013). The 90th and 10th percentile dates of first spring inflow response and recession to baseflow are March 1st and August 19th, respectively. To be conservative, a greater intensity of measurements should commence between the beginning of March and the end of August to ensure that a majority of flow is captured by the measurements.

A comparison of end-of-year estimates for 2009 between the original dataset with 2-week measurement intervals and resampled datasets with 1-month intervals indicated that increasing the measurement frequency to 1 month did not have a substantial impact on the end-of-year estimate, but did substantially impact the net inflow to some units. The end-of-year estimate for all water entering the wetland units from the collection ditch for the resampled datasets ranged from +5 percent to -3 percent errors from the original dataset (table 2). However, the end-of-year estimates for net inflow to individual wetland units ranged between +94 percent (Unit 13) to -67 percent (Unit 21). The error between resampled datasets and the original dataset for net inflow to the unit with the largest net inflow, South Marsh, was only -10 percent. This indicates that end-of-year estimates for individual units may be more sensitive to measurements frequency, whereas end-of-year estimates for the entire system are not.

Recommendation: To maintain consistency with previous datasets, to accurately estimate inflow to some units, and to adequately be able to identify and measure peak inflow to all units, spring inflow to all units (at sites that receive water directly from the collection ditch) should be collected every 2 weeks between March 1st and August 30th. For all other dates, a frequency of 1 month to 6 weeks is likely adequate. However, if early rain storms are observed prior to March 1st, it is advisable to measure and check whether a spring flow response has commenced. This recommendation is a lower priority if only end-of-year estimates for spring flow to all wetland units from the collection ditch are sought; in this case, a 1 month to 6 week measurement frequency is likely adequate year-round.

Sites to include for calculating inflow to all units are all sites where collection ditch flow is exiting to units (table 1, figure 2). This schedule should be observed for all other sites and units in which it is desirable to calculate the total surface water budget. For example, it might be useful to calculate the total flow that enters South Marsh compared to other units. If this is the case, all other sites should adhere to the same measurement schedule as described above. The spreadsheet will only calculate total net inflow for a unit if all inflows to that unit are measured.

Table 2. Comparison of errors in computation of end-of-year (annual) total flow to individual wetland units and flow from the collection ditch (which captures flow from numerous springs) to all wetland units at Ruby Lake National Wildlife Refuge in 2009, between a bi-weekly measurement frequency (default) and two resampled datasets where only monthly measurements were considered.

[meas., measurement; resample 1, dataset was filtered to only include measurements made every month starting at the beginning of the month; resample 2, dataset was filtered to only include measurements made every month in the middle of the month]

Unit	Net Inflow from bi-weekly meas. program	Net Inflow from resample 1	Error	Net Inflow from resample 2	Error
North Marsh	1,373.5	1,379.6	0.00	871.1	-0.37
Unit 10	1,220.7	1,322.9	0.08	2,257.1	0.85
Unit 13	529.7	1,025.2	0.94	412.9	-0.22
Unit 14	436.3	590.3	0.35	413.7	-0.05
Unit 20	0.0	0.0	0.00	0.0	0.00
Unit 21	356.1	117.5	-0.67	334.5	-0.06
East Marsh South	622.6	699.6	0.12	672.3	0.08
East Marsh North	723.9	763.1	0.05	832.7	0.15
South Marsh West	7,586.6	7,792.7	0.03	6,848.7	-0.10
South Marsh East	0.0	0.0	0.00	0.0	0.00
	Total Inflow	**Total Inflow from Resample 1**	**Error**	**Total Inflow from Resample 2**	**Error**
Inflow from Collection Ditch to Wetland Units	12,484.3	13,118.4	0.05	12,116.2	-0.03

Optimal Calculation Procedure

Results from the board pulling experiment were not conclusive because results varied between sites (table 3). Stabilization of flow after removal of weir boards took about 2 days for site 84 (Collection Ditch to Unit 14). However, the remaining 3 stations took longer to stabilize, in which flows did not generally stabilize until after 6/14 (3 days since the boards were pulled).

Table 3. Comparison of error in total flow calculated using two interpolation methods at 4 selected weir stations after boards were pulled from water control structures at Ruby Lake National Wildlife Refuge, June 11th to June 18th, 2013

Flow Type	Unit 10 to North Marsh		Unit 13 to East Marsh		Collection Ditch to Unit 14		Collection Ditch to Unit 20	
	Total flow (acre-feet)	Estimation Error	Total flow (acre-feet)	Estimation Error	Total flow (acre-feet)	Estimation Error	Total flow (acre-feet)	Estimation Error
Total flow using block method between 6/11 and 6/18 (default)	2.13	-0.89	20.51	-0.41	51.72	-0.05	29.79	-0.37
Total flow using linear method between 6/11 and 6/18	22.42	0.20	22.56	-0.35	29.90	-0.45	31.35	-0.34
Total flow using block method for every measurement	**18.71**	NA	**34.54**	NA	**54.33**	NA	**47.33**	NA

A short stabilization time resulted in the block-type method being a better estimator of flow than the linear-type interpolation, whereas a longer stabilization time resulted in the linear-type interpolation being a better estimator of flow. The linear-type method performed much better than the block-type method for site 65 (with an estimated error of 20 percent as opposed to 87 percent, respectively). However, the linear-type method only performed marginally better for sites 76 and 86; with an estimated error ranging from -33.7 to -34.7 for the linear-type method, as opposed to an estimated error ranging from -37.1 to -40.6 percent for the block-type method.

Use of the linear-type method may create inconsistencies with previous annual water reports or calculations. However, continued use of the block-type method will likely underestimate flow after boards are pulled for those sites in which long-stabilization times occur. **Recommendation: if a more accurate method is desired for future measurements, a new water monitoring spreadsheet should be designed that allows for linear-type interpolation. However, further investigation is needed at additional sites and for a longer period of time to determine if the linear-type method is generally more accurate overall.** Past data can be entered into the new spreadsheet format to allow for calculation of historic flows using the linear-type interpolation method.

Recommendation: if greater accuracy in inflow or total flow estimation is desired, then a frequency of measurement that is greater than 2 weeks should be used for sites in which boards are manipulated. This is especially the case if it is observed that water is close to spilling over a weir or that a spilling weir is close to going dry, or if a board is added or withdrawn. In these cases, coming back out to make repeat measurements for those sites in which boards were manipulated or in which flow is close to breaching the weir, within 2-4 days, might be desirable.

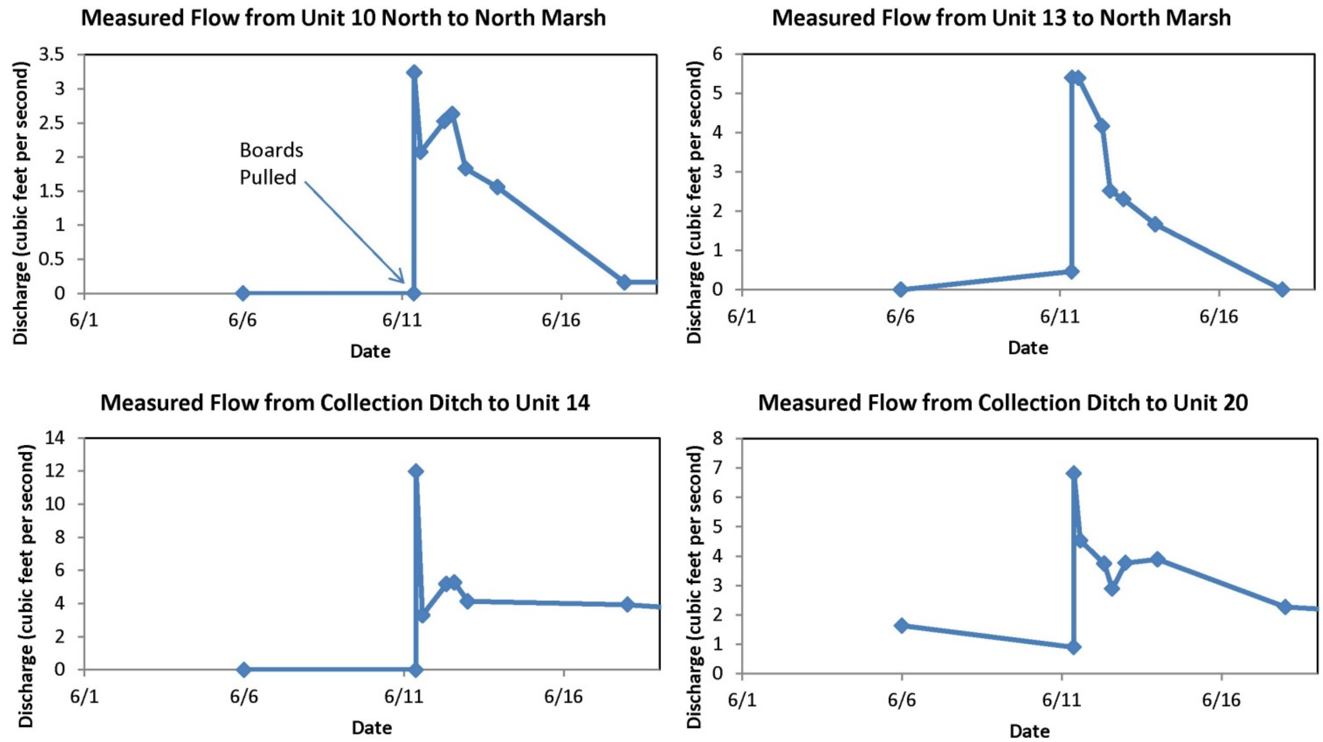


Figure 5. Discharge at weirs at 4 flow monitoring stations at Ruby Lake National Wildlife Refuge, before and after boards were pulled

References Cited

Esralew, R., and Holmes, E., 2012, Springs inventory and estimate of inflow contributions for Ruby Lake National Wildlife Refuge, May 21 -23rd, 2012, U.S. Fish and Wildlife Service Open-Access Document 18 p.: Sacramento, CA. Unpublished Report-16531, available online at https://ecos.fws.gov/ServCat/Reference/Profile/16531, acccessed March, 2013

Esralew, R., Hughes, M., Holmes, E., Epting, J., 2013. Water Resources Inventory and Assessment for Ruby Lake National Wildlife Refuge: U.S. Fish and Wildlife Service Pacific Southwest Region Inventory and Monitoring Initiative Report, 160 p.

Irrigation Training and Research Center, 2003, IRTC Weir Stick: Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo, California, USA, 4 p., available online at http://www.itrc.org/reports/weirstick/weirstick.pdf, accessed March 2013