Carmichael Subdivision Irrigation System Handbook

Richard B. Wells, PhD., PE (retired)

October 2016

Contents

Appendix: 2016 Irrigation System Statistics and Other Data

Carmichael Subdivision Irrigation System Handbook

A Guide to Irrigation Management in the Carmichael Subdivision, Boise, ID

October 2016

Purpose of this Handbook

This handbook is written to assist the Board of the Carmichael Homeowners' Association and the Board-appointed water master in making decisions about managing Carmichael's annual water ordering and the management of the Carmichael irrigation system. It focuses on technical aspects of the irrigation system. It provides useful formulas for doing various types of calculations needed for monitoring and managing the technical aspects of the irrigation system. It is divided into sections detailing the overview of the system, management practices, detailed aspects of its subsystems, techniques for estimating water usage, common problems that occur, and useful formulas for quantitatively analyzing the system.

Overview of the Carmichael Irrigation System

Figure 1 lays out the overview of the Carmichael irrigation system. Carmichael draws its irrigation water supply from the New York Canal via the Moore lateral. The system begins at the headgate to the

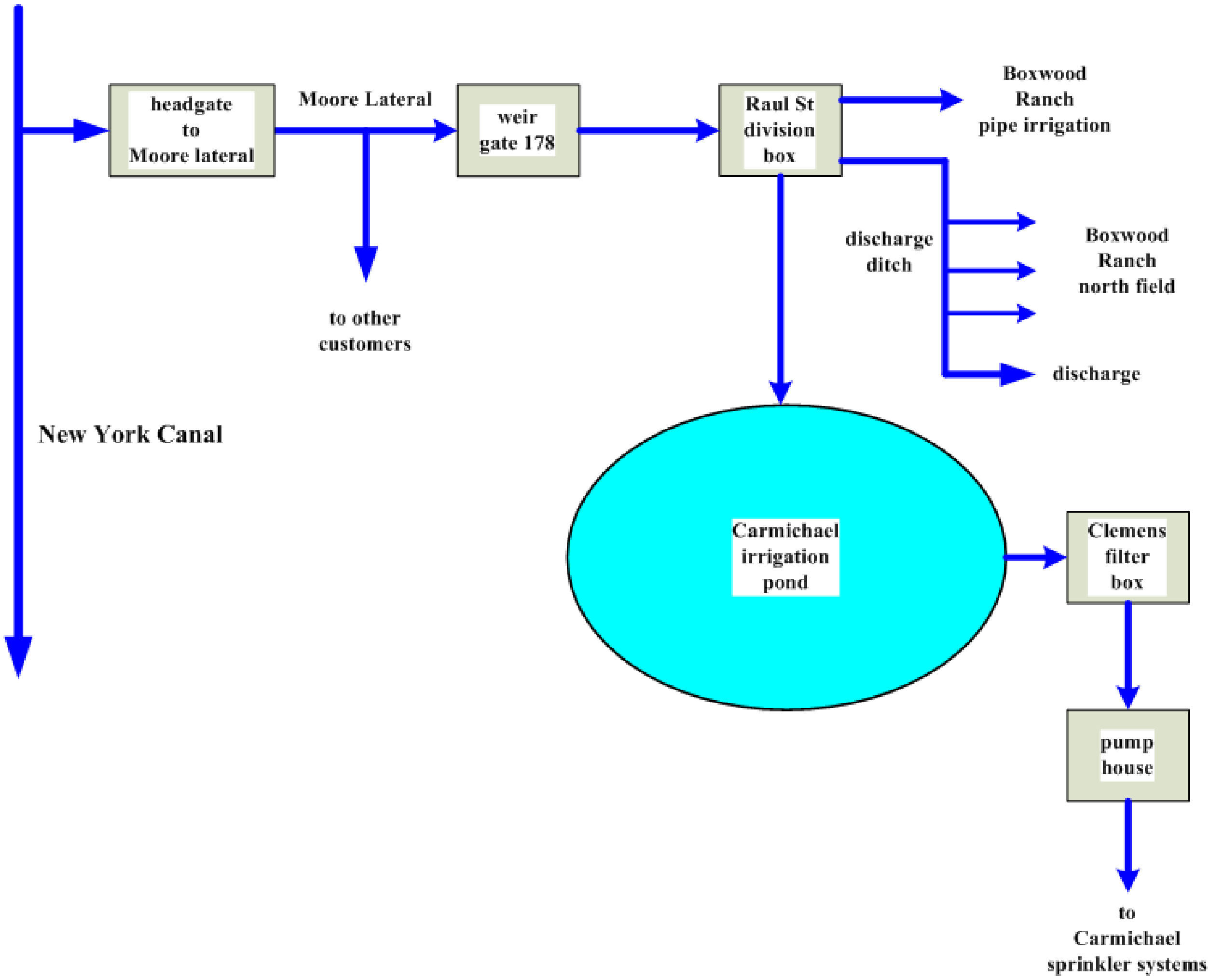


Figure 1: Overview of the Carmichael Irrigation System.

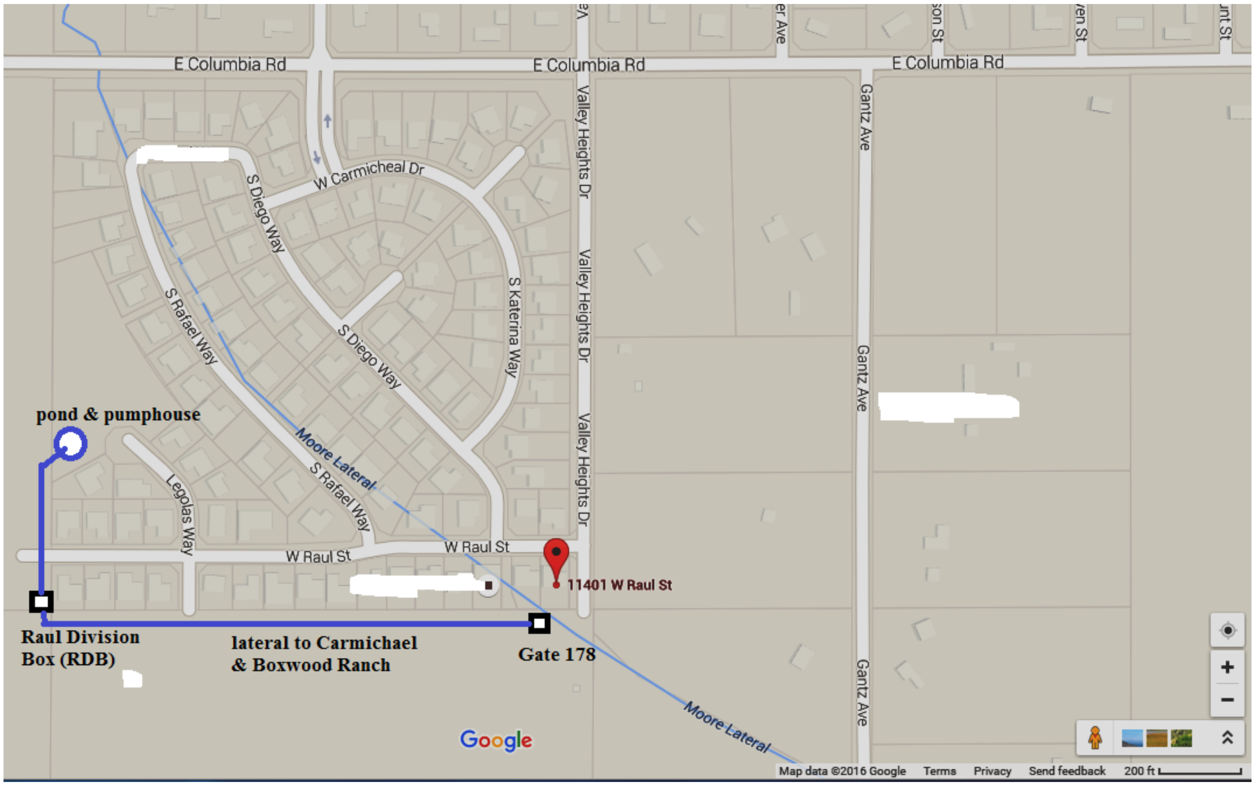


Figure 2: Locations of main elements of the irrigation system.

New York Canal. The headgate is a 3 ft. weir located at the south end of Five Mile Rd. where the Moore lateral ditch connects to the canal. Weir settings at the headgate are determined by the Boise Project's ditch rider responsible for the Moore lateral. He works in Division 2 of the Boise Project (**BP**).

Carmichael subdivision and Boxwood Ranch receive water diverted at gate 178 of the Moore lateral. This gate is located immediately south of the property at 11401 Raul St. Figure 2 shows the geographical locations of key elements of the irrigation system. Each irrigation season the Carmichael water master is responsible for ordering water from the Boise Project by specifying the number of miner's inches (MI) allocated to Carmichael from the weir at gate 178. By Idaho statute, one (1) miner's inch is defined to be 9 gallons per minute of water flow. Water flows down a buried lateral that runs from gate 178 to the Raul St. division box (RDB). From the RDB water flows to the Carmichael pond via a buried pipe. Water also flows from the RDB to the Boxwood Ranch farm south and west of the subdivision.

The pumps in the pump house draw water from the Carmichael pond. Water flows from the pond to a Clemens box on the south side of the pump house. The Clemens box is a filter for removing debris from the water before the water enters the pump well inside the pump house.

The pump house contains a pump controller, two main pumps, a jockey pump, and a final water filter. From the pump house pressurized water is supplied to the homeowners' sprinkler systems and to the various common area sprinkler systems in Carmichael subdivision. The jockey pump maintains pressure in the sprinkler lines when the main pumps are off. The main pumps are variable-speed axial pumps which are submerged in the pump house well. The pump controller controls the speeds of these pumps to maintain constant head pressure in the sprinkler line. When the water demand becomes greater than one pump can provide, the second pump is turned on to provide additional water pressure. The second pump also acts as a backup for the first pump in case that pump breaks down. There is an electric utility meter on the outside of the pump house which displays the cumulative energy consumption (CEC) of the pump house in kilowatt-hours (kW-h). CEC readings are essential for keeping track of how much sprinkler activity is going on in the subdivision. The difference in the CEC readings from one reading to the next divided by the number of hours that have elapsed between readings (**ΔE/Δt**) is a key measure of sprinkler activity in the subdivision. During the cooler months ΔE/Δt averages about 13 kW per day. During the high usage period (HUP) between about 9:00 PM and 8:00 AM, ΔE/Δt ranges from 12 to 17 kW. During low usage periods from noon to late afternoon ΔE/Δt falls to around 10 to 13 kW. A ΔE/Δt lower than 10 kW indicates minimal water consumption by the subdivision. In the hot months ΔE/Δt rises to an average of around 15 to 16 kW per day and HUP power rises to around 16 to 23 kW. (See appendix for statistics).

The Raul St. Division Box (RDB)

Figure 3 is a mechanical schematic of the Raul St. division box (RDB). The drawing is not to scale. Inside the RDB there are four smaller boxes, all of which can be viewed through the cover grating over the RDB. These smaller boxes are called cisterns. The four cisterns are: (1) the main cistern or MC; (2) the Boxwood Ranch cistern (BRC); (3) the Carmichael cistern (CC); and (4) the discharge cistern (DC). Water flows into the RDB at the main cistern (MC). From there it flows to Boxwood Ranch via a gate between the MC and the BRC. The gate setting is adjusted by the farmer according to Boxwood Ranch's irrigation requirements. The Boxwood gate is closed when there is only about 1 inch of screw protruding above the wheel that adjusts its gate. When the Boxwood gate is closed, no water flows into the BRC. The RDB ***also*** supplies Boxwood Ranch via the discharge cistern (DC).

How the RDB works in providing water to the Carmichael cistern (CC) is complicated. There is no gate between the MC and the CC. Instead, the main source of water into the CC is a small white pipe passing from the MC well to the CC. This pipe is set much higher up in the MC than the Boxwood gate.

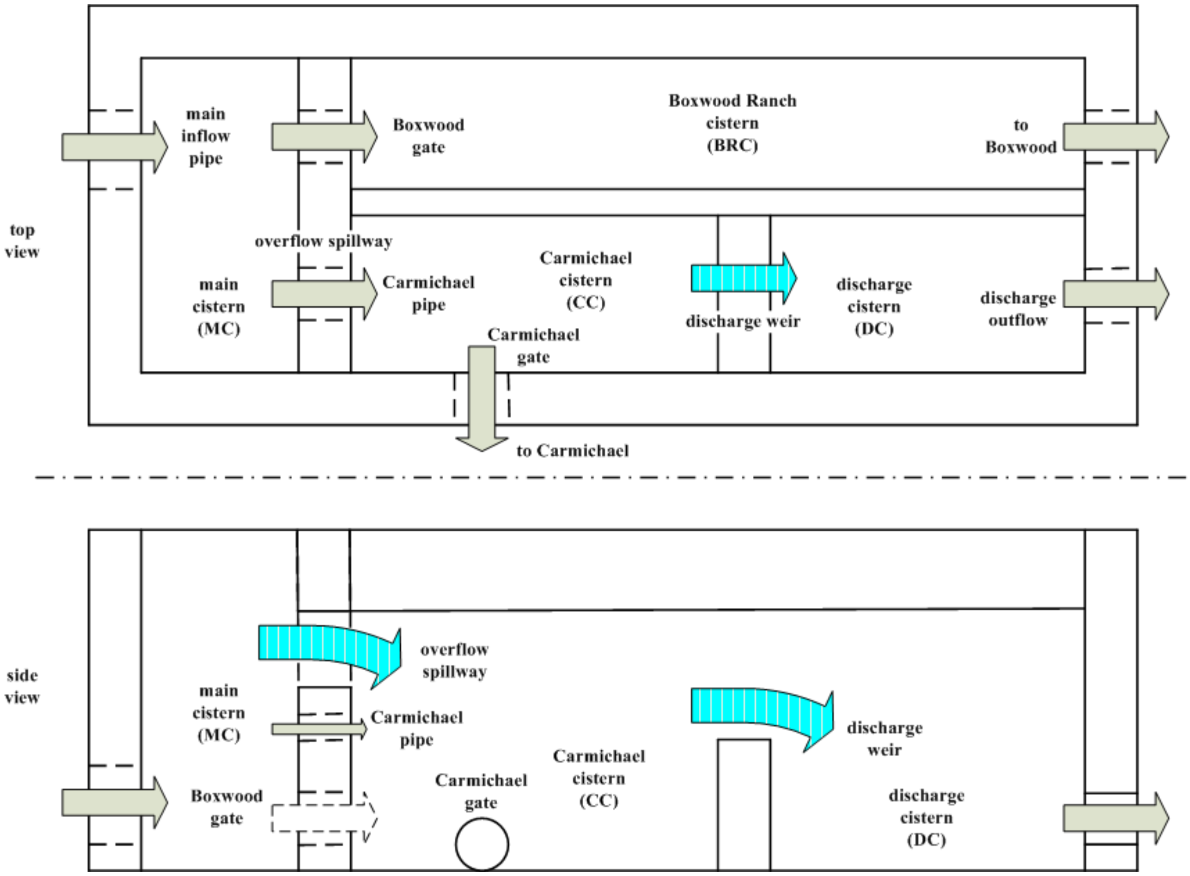


Figure 3: Top and side views of the mechanical schematic of the Raul St. Division Box (RDB). The overflow spillway is 27 inches wide. The MC is 27"×59". The CC is 27"×19.5".

Therefore, the water level in the MC must rise almost to the top of the cistern before water begins to enter the Carmichael cistern. This is a very unusual arrangement and does not conform to any standard division box design. When the white Carmichael pipe (C-pipe) is partially above the water level in the MC, a reduced flow of water into the CC results. This reduced amount is inadequate to supply the subdivision. Water can also flow from the MC into the CC via the overflow spillway between the MC and the CC.

Boxwood Ranch's irrigation is continuous. Carmichael's is not. BR divides its water between its west and south fields via the BRC and its north field via the DC. When demand through the BRC is low, water accumulates in the MC, eventually overflowing it's spillway into the CC. The spillway discharge rate into the CC varies according to Boxwood's BRC draw. When the CC overflows water spills into the DC.

When the head pressure in the CC and the head pressure in the pond are equal there is no water flow from the CC to the pond. When the flow rate to the pond is less than the flow rate from the MC into the CC, the water level in the CC will rise. When it rises to the top of the CC water begins to flow over the discharge weir (figure 3) so that the sum of the flows to the pond and the DC equals the total flow from the MC into the CC. When the flow rate to the pond is more than the flow rate from the MC into the CC then water level in the CC will drop. Pond water level also drops.

Water in the DC flows to a ditch pipe that is tapped into by Boxwood Ranch's irrigation system (figure 1). The fields north of Raul St. up to Columbia Road get their water from this ditch. Therefore this part of BR's irrigation *depends on discharge overflow from the CC*. This can and does create problems co-involving Carmichael and Boxwood Ranch. One of these is pond flooding. It is possible for water in Carmichael's pond to rise too high and flood the pump house. This is discussed later. Another is the possibility that Carmichael can unlawfully divert water from Boxwood Ranch. This is also discussed later. Both problems are caused by the RDB design and its dual uses for the discharge cistern (DC).

Inside the Carmichael cistern (CC) is a gate leading to an underground pipe that runs from the CC to Carmichael's pond. The amount of water flowing to the pond depends on the gate setting, the difference between head pressure in the CC and head pressure in the pond, and the details of the pipe conducting water to the pond. More water flows when water level in the pond drops and less water flows as water in the pond rises. This is because head pressure is proportional to the height of the water.

Water height in the MC is a qualitative indicator of how much supply flow is coming into the MC. When BR is not irrigating it provides an indication of the supply flow from the weir (W_{178}). The height of the water flowing over the MC's 27-inches-wide overflow spillway is known to vary even when the weir setting is constant and BR is not irrigating. This is due to day-to-day variations in how much actual flow comes down to the RDB from the weir. Flow rate through the C-pipe is variable and increases as MC water height increases. The amount by which it increases is not calculable. Eight consecutive HUP measurements taken from June 25 to July 4 (when BR was not irrigating) showed MC water height above the spillway (y) ranged from a low of 13/16 (0.8125) in. to a high of 1.75 in. with a mean value of 1.375 (1 3/8) in. and a standard deviation of 0.308 in. This proves that flow from the weir is not constant even when the weir setting is fixed. Because of the non-standard design of the RDB, it is not possible to calculate how much W_{178} variation there actually is, but a deviation-from-mean analysis of y suggests it is on the order of around ± 3.5 miner's inches typically. It can occasionally be much more than this.

The Irrigation Pond

The Carmichael pond has never been surveyed. It is an irregularly shaped bowl for which no exact water volume can be computed. Its total usable water volume is approximated as being comprised of a regular cylinder for about half of its perimeter and a conic frustum for its other half. These model shapes use the same maximum effective radius. Figure 4 illustrates the shape of a conic frustum.

The effective filled diameter of the surface of the pond was determined from aerial photos of the Carmichael subdivision obtained from Google Maps. To reasonable accuracy, this diameter is 62.5 ft. or 750 inches, giving a nominal filled radius of $R_{max} \approx$ **31.2 ft**. = 375 inches.

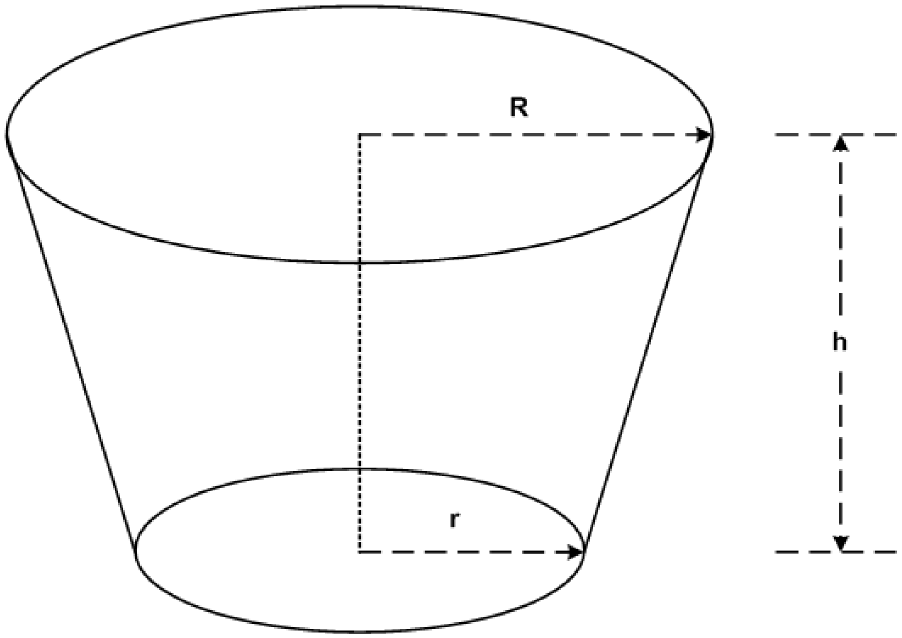


Figure 4: a conic frustum.

The base radius *r* and the usable water height *h* are determined by the low-water pump trip point in the pump house. Visual examination during a low-water pump trip that occurred May 10, 2016, showed that the usable height h_{max} is approximately $h \approx$ 4-5 ft. (48-60 inches). The examination also showed that the pond bowl is approximately a cylindrical bowl over about half of its perimeter and approximately a conic frustum over the other half. The base radius of the conic frustum is about two-thirds of its filled radius, $r = R_b \approx 20.8$ ft. or about 250 inches. This model was shown to be insensitive to h_{max} in terms of change in pond water drop D_x measured in kgal. It is a robust model because other calculations depend only on D_x.

<u>The half-cylinder volume</u>

The total volume of a cylinder of radius R_{max} and height *h* is $\pi \cdot h \cdot R_{max}^2$ where $\pi = 3.14159$. One-half of this is the pond volume contained in its cylindrical portion. In practice what is measurable during irrigation season is the drop **Δ** in ft. from the pond's normal filled water level. $h = h_{max} - \Delta$ in ft. Therefore the cylindrical volume of the pond, using $h_{max} = 5$ ft., is given by

$$V_c = \frac{\pi}{2}(5-\Delta)\cdot R_{max}^2 \approx 2.65 \cdot 10^6 \cdot (5-\Delta) \text{ cubic inches or } \boldsymbol{V_c} = \mathbf{11.5 \cdot 10^3 \cdot (5-\Delta)} \textbf{ gallons}$$

when Δ is measured in feet. 1000 gallons of water is equal to one kilo-gallon (kgal).

<u>The conic frustum volume</u>

Let Δ be the estimated drop in pond water level in feet from its nominal filled value. Then the effective water height is $h = h_{max} - \Delta = 5 - \Delta$. Let A_{max} be the surface area of the pond when it is filled. Let *A* be the surface area of the pond water when the level has dropped by Δ. Let A_b be the area of the base of the frustum. The pond's usable volume of water contained in the half-frustum is then given by

$$V_f = \frac{1}{6}(5-\Delta)\left[A_b + A + \sqrt{A_b \times A}\right].$$

Expressing the base area in units of square inches,

$$A_b = \pi R_b^2 = 181 \cdot 10^3 \text{ square inches.}$$

To calculate *A* we must first calculate the radius at the surface of the water. This is done using the Law of Similar Triangles. Let $X = R_{max} - R_b \approx 10.4$ ft. (an estimated value obtained by observing the pond during a low-water pump trip). Let the radius at the surface of the water be $R = R_b + \delta$. Then

$$\frac{\delta}{X} = 1 - \frac{\Delta}{h_{max}} \quad \text{from which we get the surface radius as } R = R_{max} - X \cdot \frac{\Delta}{h_{max}} .$$

Using this radius R we calculate the surface area as

$$A = \pi \cdot R^2 \approx \pi \cdot (375 - 25 \cdot \Delta)^2 \text{ square inches}$$

when Δ is expressed in ft.

Plugging these area values (in square inches) into the volume formula and converting V_f to gallons gives us

$$\boldsymbol{V_f = \frac{5-\Delta}{115.5} \cdot \left[181 \cdot 10^3 + A + \sqrt{181 \cdot 10^3 \cdot A}\right]} \text{ gallons when } \Delta \text{ is in ft. and } A \text{ is in square inches.}$$

The total usable volume

The total usable water volume is given by the sum of $V_c + V_f$ provided by the formulas above.

One gallon is equal to 231 cubic inches. Using the formulas above, the following usable pond water volumes as a function of Δ are tabulated in thousands of gallons (kgal).

Δ (ft.)	V_c (kgal)	V_f (kgal)	$\boldsymbol{V_{total}}$ (kgal)	**drop $\boldsymbol{D_x}$** (kgal)	
0	57.5	39.2	**96.7**	**0**	(full capacity)
0.5	51.7	33.8	**85.5**	**11.2**	
1	46.0	28.7	**74.7**	**22**	
1.5	40.3	24	**64.3**	**32.5**	
2	34.5	19.7	**54.2**	**42.5**	
2.5	28.8	15.6	**44.4**	**52.3**	
3	23	11.9	**34.9**	**61.8**	
3.5	17.3	8.5	**25.8**	**70.9**	
4	11.5	5.4	**16.9**	**79.8**	
4.5	5.7	2.6	**8.3**	**88.4**	
5	0	0	**0**	**96.7**	(drained)

The volume (V_{total}) and drop (D_x) tabulated above as a function of Δ can be approximated by a pair of straight line functions,

$$\boldsymbol{V_{total} \approx 94.2 - 19.3 \cdot \Delta} \quad \text{kgal} \qquad \text{(correlation coefficient = - 0.99896),}$$

$$\boldsymbol{D_x \approx 2.47 + 19.3 \cdot \Delta} \quad \text{kgal} \qquad \text{(correlation coefficient = 0.99895).}$$

Even though approximate, these functions are accurate enough and more convenient than the table data is for doing estimates of water consumption by observing sprinkler activity in the subdivision.

Change in the pond's water level measured at any given time is determined by two factors: (1) the flow rate of water consumed by sprinkler activity in the subdivision; and (2) the flow rate of water flowing into the pond from the RDB (called $\boldsymbol{W_{eff}}$). The Carmichael irrigation system lacks the instrumentation that is needed to obtain accurate measurements of either of these two quantities. The only thing the water master can do is try to estimate the average amount of water used and its usage rate. How to do this is explained in later sections of this Handbook. These estimates are very important for determining how many miner's inches of flow from the gate 178 weir are needed to sustain adequate water availability in the subdivision and to plan watering schedules. Data that can actually be obtained by direct inspection is used along with the formulas provided in this Handbook to obtain practical estimates of water usage and to spot and diagnose problems in the system that occur from time to time during irrigation season.

The Pump House

The Boise Project's pump house contains two main pumps plus a jockey pump that maintains about 58 psi of pressure in the sprinkler lines when the main pumps are off. The pumps are controlled by an automatic pump controller that varies the speed of the pumps as needed to maintain constant head pressure to the lines as water demand varies throughout the day. The controller also reports diagnostic data to BP's pump crew when any unexpected event causes a pump trip.

A pump trip is an emergency shutdown of the pumps designed to prevent the pumps from being damaged. There are three principal causes of pump trips: (1) a problem with the electricity supplied to the pump house by Idaho Power; (2) mechanical failure of a pump; and (3) lack of water in the pond. The error messages associated with the first two types of pump trips are "undervoltage" and "overcurrent." A few pump trips of these kinds occur every irrigation season. The system is particularly susceptible to these pump trips during thunderstorms and it is a wise precaution to check the system after every thunderstorm to ascertain whether or not it is still operating. The simplest and quickest way to do this is to manually start your lawn's sprinkler system and see if it has adequate pressure.

Low-water pump trips are serious events because a low-water pump trip only occurs if: (a) the subdivision is using more water than the irrigation pond can supply; (b) an inadequate amount of water has been ordered from the weir; or (c) some problem has occurred upstream of the RDB. From time to time the water levels in the New York Canal are changed, and this can cause problems with the setting of the headgate weir where the Moore lateral taps into the canal. Obstructions can occur in the Moore lateral or in the lateral running from gate 178 to the RDB. The water master must be prepared to work with the ditch rider to solve these problems when they occur. The primary purpose of the watering schedule is to address (a) by preventing too many Carmichael residents from watering at the same time.

The pump house has an electric utility meter attached to the side of the building. This meter displays the cumulative energy consumption (CEC) of the pump house in kilowatt-hours (kW-h). CEC readings are **essential** for gauging how much sprinkler activity has been going on in the subdivision over different intervals of the day. What one does is the following: 1) record the CEC and the time of day when you read the meter; 2) subtract from this the CEC reading taken at a previous time; and 3) divide the result by the number of hours elapsed between the two readings. The result is the average power in kilowatts (kW) consumed by the pumps during that time interval.

For example, suppose the CEC = 23,888 kW-h at 4:52 PM and the CEC = 23,911 kW-h at 6:31 PM. The difference is 23911 – 23888 = 23 kW-h and the time interval is 1.65 hours (1 hour 39 minutes). Then 23/1.65 = 13.9 kW. This quantity is denoted by the symbol **$\Delta E/\Delta t$**. **Measuring $\Delta E/\Delta t$ is essential**.

During May, 2016, the average value of $\Delta E/\Delta t$ was 12.7 kW with a standard deviation of 0.97 kW. During the high usage period (HUP) over the nighttime hours, $\Delta E/\Delta t$ rose as high as 17.1 kW and averaged 14 kW. The evening $\Delta E/\Delta t$ averaged 11.5 kW. The average ratio of evening to HUP power was 0.83 with a standard deviation of 0.10. **$\Delta E/\Delta t$ provides the best direct indicator** of high-, low-, and intermediate level sprinkling activity in the subdivision. The appendix provides all 2016 $\Delta E/\Delta t$ statistics.

Sprinkler Usage and Average Zones

The sprinkler system network of the Carmichael subdivision consists of 8 common area sprinkler zones (figure 5) and 116 house zones. (There is currently 1 vacant lot without a sprinkler system). Most of the common area sprinkler (CA) zones and all of the house sprinkler zones have multiple sprinkler stations which run one station at a time when the zone is actively watering. The water demand of the subdivision is therefore most conveniently characterized and estimated in units of sprinkler zones.

The 116 residential zones are all different from one another in terms of numbers of stations, types of sprinkler heads, and station watering times. The same is true for the common area zones. Different zones have different and unique watering requirements and these change with temperature over the season.

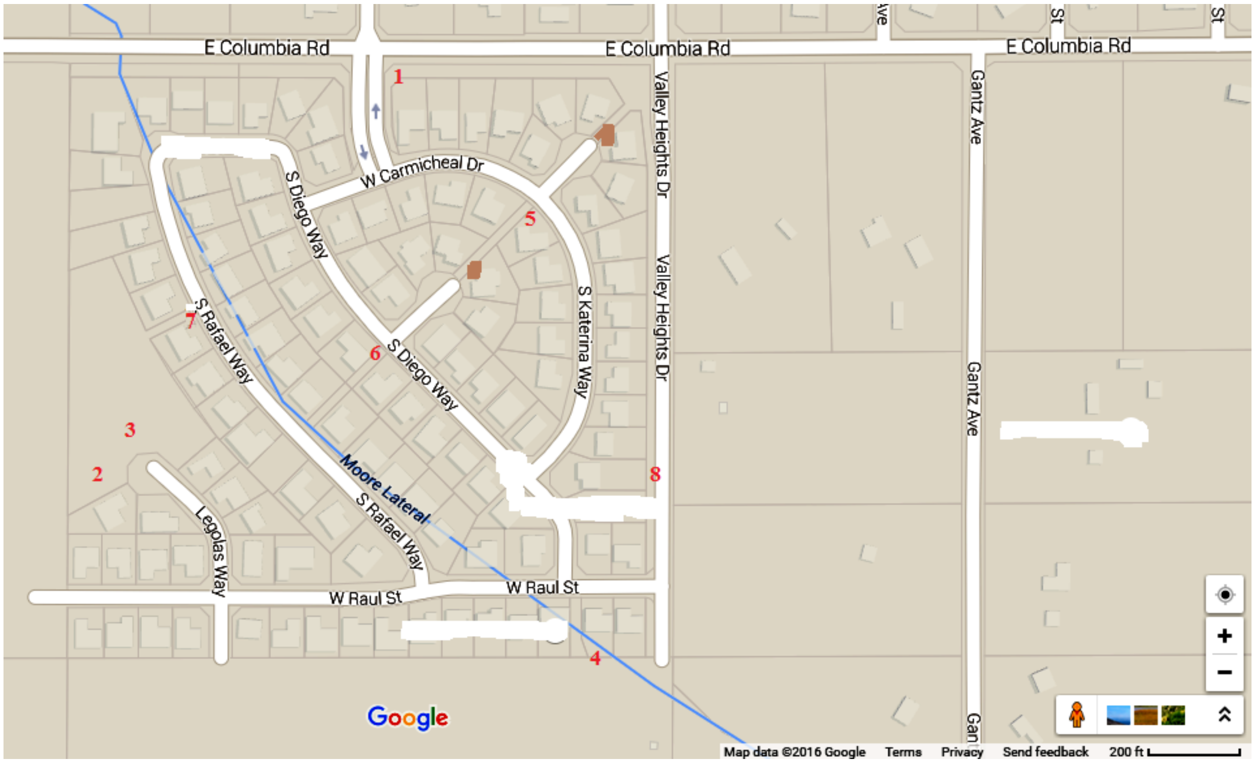


Figure 5: Locations of the timer/controllers for each of Carmichael's eight common area zones. The zones are designated: (1) Columbia Rd (CR); (2) South park (S-PK); (3) Central park (C-PK); (4) Ditch rider zone (DR); (5) Northeast zone (NE); (6) Central zone (CZ); (7) North park (N-PK); and (8) Valley Heights (VH). Five sprinkler controllers are mounted on fences at the indicated locations. The exceptions to this are: #2, #3, and #4. #1 is in a padlocked box located on the perimeter fence. The padlock combination is 5296 ("lawn"). #2 is located on the north side of the pump house next to the pump house door. #3 is installed in the ground in the green irrigation box 18 paces north of the tree well of the tree growing next to the asphalt path to the basketball court. #4 is installed in the ground at the bottom of the ditch rider's easement. Both #3 and #4 are battery operated timers.

This variability makes it necessary to estimate the subdivision's water usage profile statistically. For residential sprinkler systems a good empirical rule of thumb is that the average sprinkler head emits 2.5 gal/min of water and the average sprinkler station has six heads. Commercial sprinkler controllers operate one station at a time so **one residential zone** on the average uses $2.5 \cdot 6 =$ **15 gal/min** of water when actively watering. This is equivalent to 1.667 miner's inches (MI).

Many of the common area sprinkler heads are larger and put out more water. As an empirical rule of thumb, the S-PK, VH, and CR zones should each be treated as the equivalent of 2 residential zones.

2016 inspection data showed that approximately 78% of the Carmichael residential systems water during the nighttime and early morning hours between around 9:00 PM and 8:00 AM. This is called the *high usage period* or **HUP**. 78% of the residences is 90 residential zones. 2016 inspection data indicate the average residential zone irrigates from between about 3 to 4 hours and therefore uses between 2700 to 3600 gallons of water. If we use the average of these two figures then *in a normal non-drought year* ***38*** *zones all watering at the same time for 3.5 hours will drain the irrigation pond and trigger a low-water pump trip*. The pond is capacity limited **and this limitation mandates the use of an alternate days watering schedule** (e.g., a Monday-Wednesday-Friday rotation and a Tuesday-Thursday-Saturday rotation) to ensure there is enough water in the pond to serve the demands of the subdivision.

With alternate days rotation, it was found that an average of **43** residences watered during the first 9.5 hours of the HUP each watering day during May of 2016. Fewer than **18** watered at the same time. In June the average number of HUP waterers increased to **46** with an average of fewer than **25** watering simultaneously. Some residences water twice a day using reduced station watering times in order to counteract the effects of higher temperatures during the hot months. For these homeowners, the average time their zones are active drops to about 1.5 to 2 hours each time they run their sprinklers but their total daily usage remains the same. Doing this helps their grass develop deep root growth necessary for a healthy lawn. The majority of residences are unsophisticated irrigators and do not employ this tactic. Instead they increase their station watering times and this results in higher water demand during the HUP. About 15% cheat on the watering schedule and irrigate 7 days a week. These statistics are important considerations in planning and enforcing a watering schedule for the subdivision.

For practical purposes of water management, the number of HUP waterers, N, can be estimated by making "dawn patrol" zone counts (an irrigation inspection conducted after it is light enough to see but before the sun has time to eradicate the signs that a residence watered during the night). This generally means the inspection must begin about 20-30 minutes before solar sunrise, which is before the end of the HUP at 8:00 AM (see pg. 48). Watering activity cannot be hidden. It leaves visible signs behind. These include wet sidewalks (**WSW**), puddles in the street gutters (**P**), and active sprinklers (**A**). WSWs are visible for 3+ hours after they are made in the cooler parts of the spring and summer and for 2 hours during the hotter summertime weather. Because nighttime in the desert is cooler and more humid, puddles remain visible for more than 11 hours and are signs that watering occurred earlier in the HUP. Estimated total HUP watering is the sum total of WSW, P, and A counts plus CA zones.

Let ΔT be the time between morning pond inspection and 8:00 AM. Then $\boldsymbol{T = 11 - \Delta T}$ is the HUP time interval in hours covered by the morning inspection and $T + \Delta T$ is the HUP duration. For example, if the pond is measured at 6:30 AM then $T = 9.5$ h. It is sufficient for practical purposes of pond water management to estimate the *HUP demand* using the empirically deduced statistical formula

$$\boldsymbol{D \approx 0.9 \cdot N \cdot T \cdot d} \quad \text{kgal of water}$$

where $d \approx 1/3$ is a statistical duty cycle factor that accounts for overlapping variable-time watering by the various residences and common area zones. The statistical factor d is constrained by the inequality

$$\boldsymbol{3 \le (T + \Delta T) \cdot d \le 4} \text{ hours,}$$

which accounts for average watering duration of a residential system. The constant 0.9 is derived from the average of 15 gal/min per zone times 60 minutes per hour divided by 1000 gallons per kilo-gallon.

Part of this demand is met by pond refill flow coming from the Raul division box (RDB). When the pond is full this flow is negligible but as water is drawn from the pond this flow increases. The rest of this demand is met by water drawn from the pond that is not immediately replenished by the flow rate coming from the RDB. This is called the *excess demand*, D_x, and is estimated from the drop in pond water level Δ (in feet) using the formula

$$\boldsymbol{D_x \approx 19.3 \cdot \Delta + 2.47} \quad \text{kgal.}$$

Carmichael's *critical irrigation demand* is then given by $\boldsymbol{D_{cid} = D - D_x}$ in kgal. This is the total volume of water drawn from the CC during the portion of the HUP from approximately 9:00 PM to the time of the irrigation inspection of the pond the following morning.

Water ordering and management. For practical water management purposes it is better to re-express D_{cid} in terms of water flow rate in miner's inches. This quantity, $\boldsymbol{W_{eff}}$, is the flow rate drawn from the CC averaged over the HUP. In units of miner's inches, W_{eff} is bounded by the formula

$$\boldsymbol{W_{eff} = 1.667 \cdot N \cdot d - 1.852 \cdot \frac{19.3 \cdot \Delta + 2.47}{T}} \quad \text{miner's inches (MI).}$$

This is a key formula for water management. The factor 1.667 is 15 gallons per minute divided by 9 gallons per minute per miner's inch. The factor 1.852 is 1000 gallons/kgal divided by 60 minutes per hour divided by 9 gallons/min per miner's inch. T is the HUP inspection time interval. When N = WSW + P + A + CA the formula is an absolute bound. When N = P it is a lower bound. When N = WSW + P + CA it is a middle range estimate. Average *per day* water usage is calculated using these expressions for W_{eff}.

W_{eff} is limited by the subdivision's water order at gate 178, W_o, plus a ditch rider safety factor *when Boxwood Ranch is **not** irrigating*. When BR suspends its irrigation activities, the ditch rider resets the weir at gate 178 to eliminate BR's water order plus safety factor (typically 40 + 5 = 45 miner's inches) and closes the BRC gate (indicated by having only 1 inch of screw protruding above the BRC gate wheel at the RDB). If Carmichael tries to draw more water than its order plus safety factor then the pond will drain more (larger Δ) and water level in the CC will drop. Normally Boxwood Ranch irrigates continuously, but they do suspend irrigation from time to time. When they do, Carmichael's water order must be enough to prevent low-water pump trips. A reasonable **rule of thumb** is to order enough water W_o so that the number of miner's inches ordered (W_o) is sufficient to limit pond Δ to about 2.0 ft. for an expected HUP value of N = WSW + P + CA. If we define **W_{178}** to be Carmichael's water order plus a safety factor (in miner's inches), then the rule of thumb formula for estimating Δ is

$$\hat{\Delta} = \left[\frac{T\cdot(1.667\cdot N\cdot d - W_{178})}{1.852} - 2.47\right] \div 19.3 \text{ ft. using } W_{178} = W_o + 3 \text{ (safety factor) and } N = \text{WSW} + \text{P} + \text{CA}.$$

Factor $d \approx 1/3$. T is as explained above. The safety factor of 3 allows for variations in water level in the Moore lateral. The appendix provides statistics for CA, WSW and P from the 2016 season. Using them, the rule of thumb suggests ordering W_o = 10 miner's inches for May and 11 miner's inches for June.

*When Boxwood Ranch **is** irrigating*, water ordered by Boxwood Ranch can be steered by them to flow into the BRC *or* to cause overflow into the CC *or both*. When BR steers water into the CC, their intention is for this water to overflow the CC into the discharge cistern (DC) and go from there to irrigate their north field. However, *some of this water is diverted to Carmichael's pond during the HUP* as a consequence of how the physics of the system work. Provided that Carmichael's order is sufficient to meet its needs when BR is not irrigating, this is nothing else than the laws of physics "borrowing" water from BR and "repaying" it later as Carmichael's pond is refilled. Because BR irrigates continuously, this might or might not have ill effects on Boxwood Ranch as they recover their water later in the day. The MC discharge rate is a function of the height of water, y, above the top of the MC spillway. It is an indicator of whether BR is attempting to steer water to its north field because this discharge indicates how heavily (or not) BR is irrigating the fields supplied by the BRC. BR controls this by adjusting the row gates, which provide irrigation water to their crop rows, and adjusting the BRC gate. Unfortunately, because of the non-standard design of the RDB, it is not possible to calculate precisely how much water is discharging into the CC or how much of it in excess of Carmichael's water order is being diverted to the Carmichael pond. The farmer and water master must work cooperatively to manage overall irrigation.

If W_{178} is under-ordered, then water diversion at the CC *does* result in some of BR's water being "rustled" by Carmichael subdivision. Water rustling is unlawful. The BR farmer can tell if this is happening by looking at the discharge cistern. If it is drained, then he knows his water is not reaching it and there is only one other place for this water to go: Carmichael subdivision.

The water order must be large enough to refill the pond during the lower usage periods of the day but not so large that too much of the subdivision's water flows into the discharge cistern (DC). In ordering water, a tradeoff is required in order to meet these two conditions. To understand this tradeoff it is necessary to understand real-world facts that affect Carmichael's water usage and supply. These produce large random day-by-day fluctuations. These facts are discussed next.

Draw-down and Refill. It is a matter of common sense that if the flow rate of water demanded by Carmichael consumers exceeds the supply rate of water coming into the Carmichael cistern (CC) then water drawn from the pond is not fully replenished by water flowing down from the weir at gate 178 into the CC. Therefore the water level in the pond will be drawn down. Contrariwise, if the Carmichael demand is less than the supply flowing into the CC, the water level in the pond will rise until head pressure at the pond and head pressure at the CC are equal. As head pressure difference increases water flows to the pond at a faster rate, and as it decreases water flows to the pond at a slower rate.

As a practical matter of water management, instantaneous flow rate to the pond is not as important as average flow rate ($\boldsymbol{W_{eff}}$). The average flow rate is how Carmichael's stop-and-go irrigation approximates the continuous-flow agricultural irrigation operations that southwest Idaho's system of dams, reservoirs, and canals was designed to serve. When Boxwood Ranch is not irrigating, the average rate cannot exceed the supply from gate 178, which is the sum of Carmichael's water order plus a ditch rider safety factor. When BR is irrigating its north field, then it is possible for the average rate W_{eff} to exceed Carmichael's water order plus safety factor for part of the day. This can only happen during a high usage period (HUP). Excess W_{eff} during HUPs <u>has</u> been observed during normal operation of Carmichael's irrigation system.

Other factors also affect flow rate to the pond by affecting the water level in the RDB's main cistern (MC). For example, sometime during the night of June 13 or early morning hours of June 14, 2016, a vandal opened a butterfly valve in BR's pipe from the BRC. This diverted enough water from the MC to reduce the water supply to the CC from 12 miner's inches to a flow rate insufficient to refill the pond during the day plus keep up with the high demand during the next HUP. It resulted in a low-water pump trip at 12:03 AM on June 15. It also deprived BR of its irrigation water on those days.

Sometime during May 9-10, 2016, an obstruction upstream in the Moore lateral reduced the flow from gate 178. That event triggered a low water pump trip at 4:00 AM the morning of May 10. It took until 9:35 AM to begin refilling the pond. It took until 3:00 PM for the CC to refill and the pond to recover to a $\Delta = 1$ ft. On May 13, 2016, a problem at the headgate to the New York Canal reduced water flow in the Moore lateral such that Carmichael was receiving only about 5 miner's inches of flow from gate 178. That problem was discovered during the evening pond check and was corrected in time to prevent another low-water pump trip the night of May 13-14 by calling the ditch rider to come out at 7:30 PM.

Boxwood Ranch. Another source of variability is unpredictability of the farmer's day-by-day irrigation activities. He visits the RDB several times a day to check on it and sometimes to make changes in the BRC's gate setting. His first trip to it is in the mornings and usually happens before 6:00 AM. This means conditions at the RDB after 6:00 AM are not necessarily the same as earlier during the HUP.

The farmer has days when he irrigates specific fields and days when he does not. When he plans to cease irrigating altogether for awhile he notifies the ditch rider, who closes the BRC gate and readjusts the weir setting at gate 178. The BRC gate is closed when there is only about 1 inch of bolt protruding above the gate wheel. The height of this bolt above the gate wheel is the only way for an inspector to know whether or not there is water flowing through the BRC to BR's west and south fields.

When the farmer is irrigating, he does not always draw the same amount of water through the BRC. His day-to-day decisions are based on factors influenced by weather and the condition of his crop. When his actual flow is lower, this makes water in the MC rise and eventually spill over the MC weir into the CC. Boxwood Ranch requires and uses a much higher flow from gate 178 than Carmichael does. He typically orders 40 miner's inches from the weir and the ditch rider adds a safety factor of 5-10 miner's inches to this. Carmichael's typical order is less than or equal to 12 miner's inches and its supply plus additional safety factor does not exceed 22 miner's inches. During the day this flow fills the CC to the point of overflowing into the DC. Oftentimes this overflow is so much that it produces "whitewater" (WW) in the DC spillway and roiling water in the DC itself. To some degree Carmichael benefits from this because it raises the head pressure in the CC and produces faster flow into the pond than there would be otherwise. In effect it decreases the amount of water drawn from the pond in excess of pond inflow and this results in smaller pond drops Δ.

This does not necessarily mean Carmichael is under-ordering water from the weir. Insofar as the Boxwood Ranch cistern (BRC) is concerned, its condition is entirely under the control of Boxwood Ranch irrigators. The farmer can inadvertently give *us* some of his water, but nothing we can do can *take* water away from the BR cistern (BRC). However, this is not the whole story.

The field north of Raul St. and south of Columbia Road receives its irrigation water from the RDB's discharge cistern (DC) via a white pipe in the north ditch (the Boxwood Ranch ditch). In order to irrigate this field, Boxwood Ranch must deliberately steer some of its water into the discharge cistern because the DC is the sole source of irrigation water for the north field. The farmer steers some of his water to the DC by reducing the opening of the BRC gate. This decreases flow into the BRC and causes the water level in the main cistern (MC) to rise until it tops the overflow spillway and pours into the Carmichael cistern. The farmer's intention is to deliberately cause the Carmichael cistern (CC) to overflow into the DC. Water from the DC then flows to his north field.

When he is doing this, the overflow from the MC is impressively visible. When water is not being steered deliberately to the DC, the water depth over the spillway averages about 1.7 inches. When he is steering water to the DC, the water depth over the spillway can be 2.5 to 3 inches. Boxwood's typical water order is for 40 miner's inches and it is allocated an additional safety factor from the gate 178 weir setting. [Note: an inch of water over the spillway is **not** equivalent to a miner's inch].

If Carmichael's water master orders less water from the weir than the subdivision actually consumes, some of the water Boxwood Ranch tries to steer to the DC is intercepted at the CC and flows to the pond. This is the "water rustling" situation discussed on page 11 earlier.

Pond Flooding. Boxwood Ranch can have a second effect on Carmichael, and this one is not good. It is a confirmed fact that it is possible for the Carmichael pond to flood. This happens when the water level in the DC rises to the point where it becomes higher than the wall between the CC and the DC. When this happens it has the effect of causing the CC and the DC to become one large cistern with two outlets. As water level rises in this unintended "super-cistern" its head pressure goes up and forces more water to flow to the pond. This increases water level in the pond. This increase also increases water level in the pump house well. By convention we say the pond is flooded when this well water reaches the top of the well and begins flowing into the pump house itself. It is putting it mildly to say the Boise Project pump crew gets a little upset when this happens. Pond flooding does not threaten the houses near the pond because the flood water around the pond doesn't get high enough to do this, but it does threaten to damage the pump house walls and electrical equipment inside the pump house.

What causes this? Remember: Boxwood Ranch taps into the discharge ditch to irrigate its north field. In order to supply water to the crop rows the hired irrigators employed by BR increase the flow from the discharge cistern. They do this by partially closing the BRC gate and forcing more spillover from the MC into the DC by way of the CC. This causes the water level in the DC to rise. If the flow rate into the DC exceeds its outflow capacity, the CC and DC merge and this causes a pond flood. The same thing can happen if an obstruction plugs up the BR irrigation pipe from the BRC. That happened on April 27th of 2016 and again on May 25th. (April and May are the months when most problems occur in the system).

This is one reason why it is a good practice to inspect the RDB regularly. If the rising water in the DC is spotted in time, the water master can call the Boxwood Ranch farmer (Lou). He will then come out and open the BRC gate to draw down the overflow from the MC and prevent the formation of a "super-cistern." He will also instruct his irrigators about the situation and instruct them to avoid over-filling the discharge cistern so that it doesn't backfill into the CC.

The New York Canal and Moore Lateral. The water authorities occasionally make adjustments to how much water is flowing in the New York Canal. They sometimes raise it and they sometimes lower it. In either case, it changes the flow from the headgate weir where the Moore Lateral taps into the canal (figure

1). This shows up a few hours later as a change in water level in the ditch immediately upstream of gate 178. Water level in the Moore lateral is also affected by other users' water draw. Drops of 6 inches or more in the Moore lateral do happen. Change in this water level has the same effect as changing the weir setting at gate 178. It results in less flow into the RDB when the ditch level drops and it results in more flow into the RDB when the ditch level rises. Unless the ditch rider compensates by adjusting the headgate or the weir, the effect can be either too little or too much inflow into the RDB. On May 9 of 2016 a reduction of water in the Moore lateral caused a severe drop in the water level in the MC. It dropped our inflow to the equivalent of about 4 miner's inches. At 4:00 AM on May 10 the pond was drained and triggered a low-water pump trip. A similar situation occurred on May 13 but was spotted at the RDB during the water master's evening irrigation system inspection. The ditch rider was called out at 7:30 PM to readjust the weir setting to compensate for the day's undersupply of water. On August 2-3 a 5 inch drop in the Moore lateral produced a 2.5 ft. drop in pond water level during the HUP of August 3rd. Ditch water level in the Moore lateral and cistern water levels in the RDB must be regularly checked to guard against draining the pond.

Water Allowance and Water Ordering. Boise is located in high desert country where water is a vital but limited resource. The system of dams and reservoirs providing water to the Treasure Valley is jointly managed by state and federal authorities. These two authorities have a sometimes rocky relationship with each other because they have different primary objectives that sometimes clash. Speaking in a broad generalization, the state authority tends to prioritize the state's irrigation needs while the federal authority tends to prioritize protection of the dams, fish, and wildlife habitat. The state, of course, also has protection of the dams, fish and wildlife habitat on its priority list, and the federal authority has the state's irrigation needs on its priority list. They merely differ as to what has the *higher* priority if circumstances of weather, rainfall, and melting snowpack produce a conflict in serving *all* these priorities.

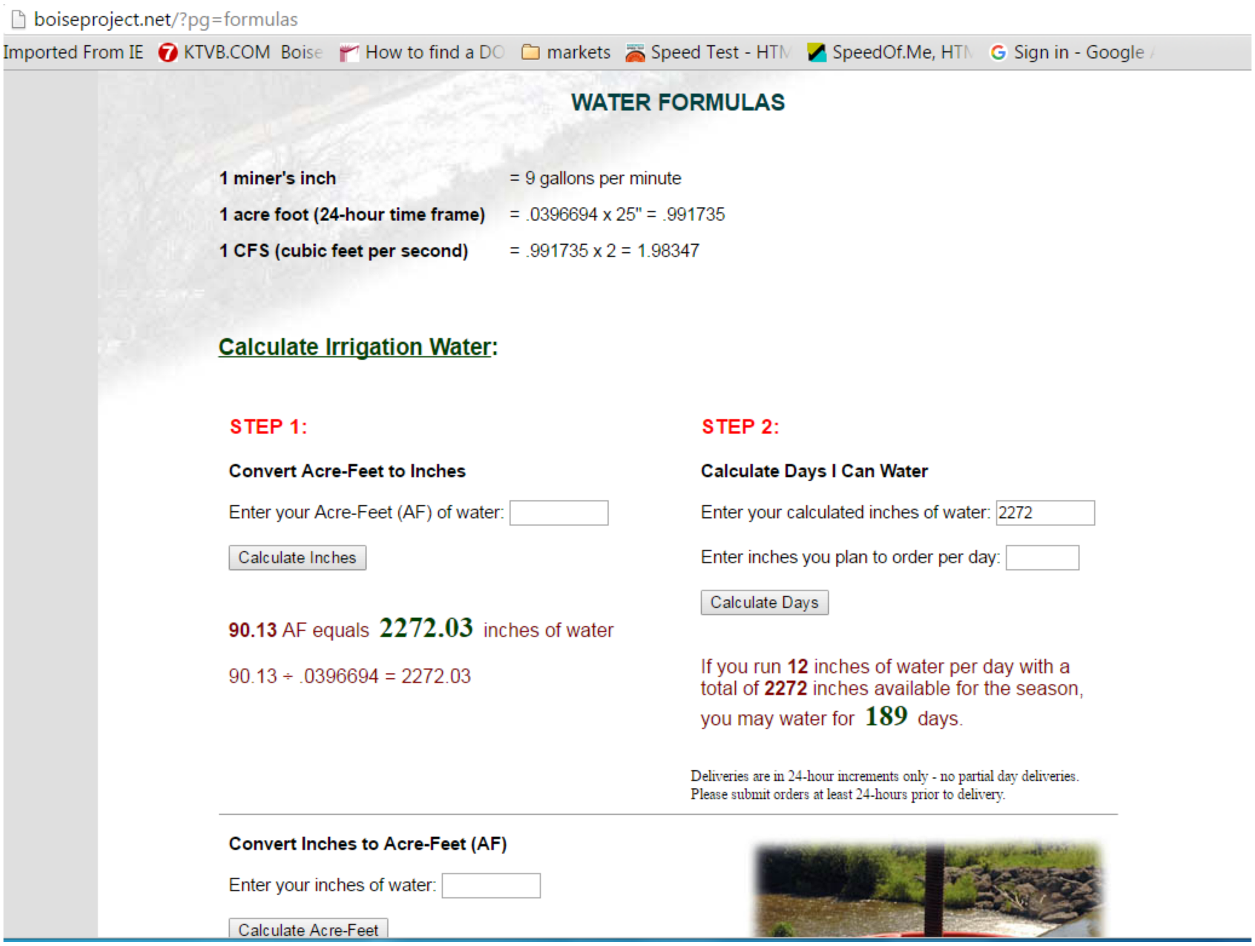
The effect this has on us is that each year, in April, the water authorities allocate an ***allowance*** of water from the reservoirs. The April allowance is reviewed in June and can be replaced by an ***allotment***. Each user is allocated a specific number of acre-feet (AF) of water at the reservoir. In non-drought years Carmichael subdivision's normal allowance is 3.75 AF/acre. This number is multiplied by the number of acres for which the irrigation tax has been paid. In Carmichael's case this is usually around 32 acres. Thus, in a normal non-drought year we have a total of 3.75 · 32 = 120 acre feet of irrigation water supply. With proper water management this allowance is sufficient to meet the subdivision's irrigation requirements for the season with some to spare. At the end of the season, any water remaining is stored at the Anderson Ranch reservoir and can be used by Carmichael the following year. Our stored water is in some ways like a kind of "water bank account" with some important differences I discuss below.

In drought years, the allowance can be significantly reduced. For example, in the 2015 drought year Carmichael's allowance was only 45% of our normal allowance (1.7 AF/acre). This was not enough water to see us through the irrigation season. (The nominal irrigation season is 183 days from about April 15 to about October 15). The only reason the subdivision was able to make it through the irrigation season in 2015 was because in prior years Carmichael's water management "banked" 1.1 AF/acre of water. This gave us a total of 2.8 AF/acre available to "spend" in 2015 (1.7 + 1.1 AF/acre).

The number of days we can irrigate depends on the number of miner's inches ordered from the weir and the number of paid acre feet of water allowance. This is determined by water formulas for converting paid acre feet into an equivalent number of miner's inches of water and then calculating the number of watering days at a given number of miner's inches ordered from the weir at gate 178. The Boise Project provides a very useful water calculator on their web page at URL

boiseproject.net/?pg=formulas .

Figure 6 is a screen shot of this web page showing an example calculation. The example uses allowance numbers, including our stored water reserve, from the 2015 irrigation season (90.13 paid acre feet) and calculates the number of water days assuming a weir order of 12 miner's inches. The result is 189 days.



WATER FORMULAS

1 miner's inch = 9 gallons per minute
1 acre foot (24-hour time frame) = .0396694 x 25" = .991735
1 CFS (cubic feet per second) = .991735 x 2 = 1.98347

Calculate Irrigation Water:

STEP 1:

Convert Acre-Feet to Inches

Enter your Acre-Feet (AF) of water:

90.13 AF equals **2272.03** inches of water

90.13 ÷ .0396694 = 2272.03

STEP 2:

Calculate Days I Can Water

Enter your calculated inches of water: 2272

Enter inches you plan to order per day:

If you run **12** inches of water per day with a total of **2272** inches available for the season, you may water for **189** days.

Deliveries are in 24-hour increments only - no partial day deliveries.
Please submit orders at least 24-hours prior to delivery.

Convert Inches to Acre-Feet (AF)

Enter your inches of water:

Figure 6: example of using the Boise Project's on-line water calculator.

Given the allowance number of paid acre feet (90.13 AF in the example), this is converted to units of "miner's inch-days" (called "inches of water" in figure 6). This is done by dividing the allowance number of paid acre feet (90.13) by 0.0396694 (a rather byzantine number derived from the physics of gravity flow irrigation systems). In the example this gives 2272 "miner's inch days." This number divided by the number of miner's inches ordered at the weir gives the number of watering days (189 days in the example). Water is only delivered in 24-hour increments, so any fractional amount of a day is truncated. (2272 ÷ 12 = 189.333, which is truncated to 189 days). The miner's inches ordered must be an integer.

To recapitulate the water order arithmetic:

1) get the allowance from the Boise Project (e.g. 3.75 AF/acre)
2) multiply by our paid acres to get total acre feet (e.g. 3.75 × 32 = 120 AF)
3) divide by 0.0396694 to get "inches of water" (e.g. 120 ÷ 0.0396694 = 3025)
4) divide by the weir order to get number of watering days (e.g. 3025 ÷ 12 = 252).

Table I illustrates five cases of watering days vs. water order (W_o) for five different water allowances. From left to right, the example allowances in AF/acre are: 1.1; 1.7; 2.6; 2.8; and 3.75. These are allowance numbers as obtained from the Boise Project (step 1 above). The 1.1 AF/acre value corresponds to Carmichael's water carryover amount from 2014. The 1.7 AF/acre number was Carmichael's 2015 allowance from BP. The 2.8 AF/acre number is the sum of these two. 3.75 AF/acre is a normal allowance in non-drought years. 2.6 AF/acre is the *allotment* for Carmichael issued by the BP on June 15th, 2016.

Table I: Watering Days vs. Water Order Amount

W_o	watering days for allocated inches				
(miner's inches)	901 in.	1371 in.	2097 in.	2272 in.	3025 in.
8	113	171	262	284	378
9	100	152	233	252	336
10	90	134	210	227	303
11	82	125	**191**	207	275
12	75	114	175	**189**	252
13	69	105	161	175	233
14	64	98	150	162	216
15	60	91	140	151	202
16	56	86	131	142	**189**
allowance:	1.1	1.7	2.6	2.8	3.75 AF/acre (at 32 paid acres)

In non-drought years the nominal irrigation season is **183 days** (April 15 to October 15). Table I shows that Carmichael's carryover into 2015 (901 inches, corresponding to a 1.1 AF/acre allowance) did not provide enough water for an irrigation season. Carmichael's new allowance in 2015 (1.7 AF/acre) also did not provide enough water to get through the 2015 season. However, their *sum* (2.8 AF/acre) *did* provide enough water to make it through the summer of 2015 at a weir order of 12 miner's inches. What this illustrates is the importance of managing Carmichael's irrigation in non-drought years to "bank" enough water at the end of the season as a reserve if the next year should be a drought year. The Boise Project maintains a ledger of how much water is ordered by the subdivision each irrigation season and calculates at the end of that season how much stored water is credited to the subdivision's account for the following season. BP provides this number when the new year's allowance is issued each April. The web site is http://www.boiseproject.net/wateraccounting/WaterSummary.aspx . This page has a password.

However, there are two important additional factors which concern stored water. First, credited stored water cannot be stored indefinitely. Each year the stored water reserve is "depreciated" by 20%. So, for example, if 1000 inches (miner's inch-days) is stored this year from the previous year and not used, then next year this will be reduced to 800 inches; the following year to 600 inches; etc. In five years there will be zero water remaining in the "water bank account" from that initial 1000 inches.

Second, the stored water is regarded as being stored in the Anderson Ranch reservoir. In some non-drought years, the water authorities deem it necessary to do a flood control release of water from the Anderson Ranch reservoir. When they do this *all stored water from all accounts is lost*. For example, if Carmichael subdivision had stored 1000 inches at the end of the irrigation season and the following spring a flood control release of water from Anderson Ranch Reservoir is made, that 1000 inches is gone and Carmichael subdivision is given an ***allotment*** of water. Allotments can potentially create a problem in managing Carmichael's water reserves for dealing with multiple-year drought years (see pages 32-34).

As Table I illustrates, the normal allowance of 3.75 AF/acre is more than sufficient provided the subdivision orders less than 16 miner's inches. This is because the subdivision would have 189 watering days at 16 miner's inches, and the subdivision is amply supplied with irrigation water at an order of W_o = 12 miner's inches if proper water management is used and enforced. An established lawn only requires a one (1) inch covering of water per week to maintain healthy growth and an attractive appearance. This means it is not necessary to water more than three days a week, and therefore alternate days rotation schedules for homeowners are sufficient to provide them with all the water their lawns actually need. Indeed, watering a lawn more than this is unhealthy for the lawn because over-watering removes nutrients from the soil, promotes the growth of fungus, and promotes shallow root growth in the grass. Shallow root grass is particularly vulnerable in drought years.

Suppose that in a nominal non-drought season (183 days) Carmichael has 32 paid acres and orders 12 miner's inches from the weir throughout the entire season. At a 3.75 AF/acre allowance, W_o = 12 miner's inches provides a 252 day supply of water. Therefore, at the end of the season the subdivision would "bank" a 252 minus 183 = 69 days reserve. The stored inches of water would then be 12 miner's inches per day times 69 days = 828 inches, which is equivalent to 828 times 0.0396694 = 32.8 paid acre feet. This is equivalent to a pseudo-allowance of 32.8 ÷ 32 paid acres = 1.02 AF/acre. This is only slightly less than Carmichael subdivision's carryover from the 2014 irrigation season shown in Table I.

In drought years, loss of stored water because of a water release at Anderson Ranch Reservoir would leave the subdivision with a shortage of irrigation water. Fortunately, in a drought year there is rarely any reason for a flood control release from the Anderson reservoir to be necessary. Flood control is needed only when there is so much water coming into the reservoir that it threatens the dams. Almost by definition a drought year is one in which too *little* water is coming into the reservoir.

However, it is always possible for somebody to make a mistake. In 2013 there were allegations made by lawn care companies and canal operators that the water authorities had released too much water prior to the start of irrigation season. It left Carmichael subdivision with a severe shortage of irrigation water and a shortened irrigation season. That season ended September 5th (40 days short of a nominal irrigation season). In 2014 the irrigation season was ended by the water authorities on October 4th, 11 days short of a nominal season. When something like this happens, it is unfortunately also usually accompanied by hot, dry weather in August and September. What can the Association do in such an event? The only recourse in such an event is that homeowners are forced to use city water instead of irrigation water to satisfy their watering needs. People do not like this because city water is more expensive than irrigation water and running hoses is time consuming. Nonetheless, this is the action of last resort, and in this event water management is a private matter outside the jurisdiction of the Homeowners' Association. The Association has no jurisdiction over the use of city water. It *can* relax covenant requirements on lawn appearance.

In every irrigation season, the season divides into times of 'cooler weather' and a time of 'hot weather.' Generally speaking, homeowners tend to use less irrigation water in the 'cool season' than they use during the 'hot season.' Water demand is seen to rise in the summer months, typically beginning in mid-June. Good water management practice dictates ordering less water during cool weather and more water when the hot summer weather arrives. W_o in a 'cool season' is dictated by the requirement to avoid draining the irrigation pond without water rustling. As a rule of thumb, the 'hot season' can be defined by when daily temperatures exceed about 80° consistently. Historically this happens around June 11 but there is a considerable variation in this. For example, in 2016 sustained hot weather began on May 29. The water master needs to keep himself informed of the long range temperature forecast in order to make informed decisions about his water orders W_o. (Historical weather data is provided in the appendix).

For example, suppose we have a nominal irrigation season of 183 days and that the onset of hot weather does occur on June 11. From April 15 to June 11 is 57 days. Suppose that during this time W_o is 10 miner's inches. Using 2016 average HUP May demand levels, this order would drain the pond by about 2.6 ft. during the HUP. In actual practice the drain would be less than this because of the 'safety factor' added by the ditch rider at the gate 178 weir. An approximately 1.3 ft. pond drop would be more typical of actual conditions. Ordering 10 miner's inches a day for 57 days would consume 10 × 57 = 570 inches of allowed water out of the total of 3025 inches (see Table I). That would leave 3025 – 570 = 2455 inches for the remaining 183 – 57 = 126 days of the irrigation season.

Now suppose that after 57 days the water order is increased to 12 miner's inches for the remainder of the irrigation season. That will consume 12 × 126 = 1512 inches of water out of the 2455 remaining allowed inches. Therefore, at the end of the irrigation season the subdivision would "bank" 2455 – 1512 = 943 inches (equivalent to 37.4 paid acre feet or about a 1.2 AF/acre allowance).

This example illustrates the sort of "water bookkeeping" the water master must do each season to best conserve Carmichael's water and lay in a stored water reserve in case the following year is a drought year. Notice that it consists of two parts: 'cool weather' orders, which are dictated by pond drop limits; and the 'hot weather' order, which is motivated by the necessary precaution to "bank" water for the next season.

Water management becomes more challenging when there are two or more consecutive drought years. 2013 through 2015 were all considered drought years in the Treasure Valley and southwest Idaho. The subdivision entered the 2015 watering season with a total allowance of water of 2272 inches (Table I). That year Carmichael's water master ordered 7 miner's inches for the early season (through about mid-June) and 9 miner's inches for the rest of the season. The irrigation pond was never observed to drop more than about 3.5 ft. at any point in the season. This implies that during the HUP the amount of water drawn from the CC exceeded 13 miner's inches. This, of course, exceeds both the 7 and 9 inch water orders and implies that the subdivision was consuming at least 4 to 5 miner's inches of the safety factor *during the HUP*. Measurements were not being taken in 2015, so it cannot be established what the *average* usage was over the course of a full day. 2015 was a controversial year because that year the Boxwood Ranch farmer complained to the ditch riders that he was having to increase his water order because Carmichael had under-ordered water. The ditch riders believed this was true. Carmichael's water master did not.

The basis of this allegation could only have been the farmer's observation of how much water he was able to steer into the discharge cistern when irrigating his north field. It is almost certainly true that during most of Carmichael's HUP there would have been very little to no water getting past the Carmichael cistern into the DC unless Boxwood Ranch steered most of its water supply to the DC. BR did increase its water order that year – which is why the complaint was made – presumably to support simultaneous irrigation of the north field and the fields served directly from the Boxwood Ranch cistern. There is no doubt that Carmichael was tapping into the ditch rider's safety factor that year during the HUP. It also is possible that the subdivision might have tapped into Boxwood Ranch's water order. The more aggressive use of the pond's capacity as a water buffer certainly had enough effect on BR's north field irrigation operations (because of draining the DC during the HUP) to be noticed by the Boxwood Ranch farmer. It is certain, too, that southwest Idaho will continue to experience multiple-year droughts in the future, and the water master must be cognizant of and sensitive to Boxwood Ranch's concerns. Such concerns are, of course, heightened for all parties during drought years.

Measuring Pond Drop

Measurement of the water level in the pond is a very important measurement in ascertaining the subdivision's use of irrigation water and determining the subdivision's water order. The Carmichael pond is not equipped with a staff gage, such as the USGS uses to measure water height in rivers, and so some alternative method must be used to determine pond drop Δ. It is desirable that this method not require any expensive tools and that it be easy enough to perform that very little training is required for an observer.

The method I recommend is called the "ruler gauge" (RG) method and requires nothing more than a standard wooden ruler such as those sold in grocery stores. It is based on the same principle ancient Greeks used to measure the height of Egyptian pyramids, the Law of Similar Triangles (figure 7).

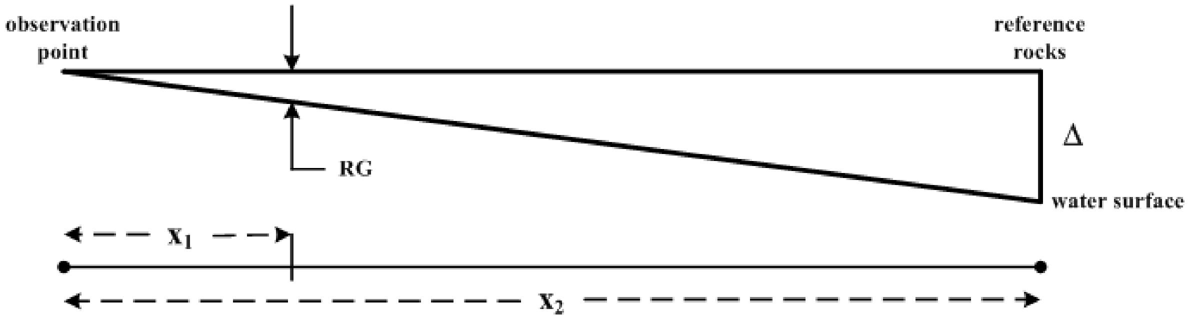


Figure 7. Geometrical illustration of measuring pond drop Δ by the Ruler Gauge (RG) method.

Figure 8. Observation and reference points for measuring drop in pond water level by the ruler gauge method. Also shown is the location of the pipe from the pond to the Clemens box.

The Law of Similar Triangles states that the ratio of height RG to distance X_1 in figure 7 is equal to the ratio of pond drop Δ to distance X_2, i.e.,

$$\frac{RG}{X_1} = \frac{\Delta}{X_2} \quad .$$

To use this method, it is necessary to know distances X_1 and X_2. A ruler is used to measure RG and Δ is then calculated from the other three numbers.

X_2 is obtained by making the observations from a predetermined location (the **observation point** shown in figure 8). X_2 is the distance from the observer to a layer of **reference rocks** (marked in figure 8) on the other side of the pond. The reference rocks are located in front of the **reference tree** indicated in figure 8 along the observer's direct line of sight. The observation point is at the pond fence midway between the two trees shown in figure 8 at the third fence panel away from the fence's gate. Distance X_2 is determined from the aerial photograph (figure 8). For a male of average U.S. height (5' 9.5") X_2 is **78.3 ft**. (76.5 ft. plus 21.5 inches for the arm's length of a male of average U.S. height).

To make the measurement, place the ruler flat against the fence ***at arm's length***. Distance X_1 is the distance from the observer's eye to the ruler. For a person of average height for U.S. males (5' 9.5"), this distance is **21.5 inches**. Sight along the ruler to the top of the reference rocks and place the tip of your thumb on the ruler level with the pond water surface. This gives you the measurement height RG.

Standard rulers are marked off in sixteenths of an inch. If RG is *n*-sixteenths inches then to an accuracy of within a few inches the pond drop is **$\Delta \approx 0.22 \cdot n$** ft.

Inspections and HUP Water Usage Estimation

Having adequate knowledge of approximately how much irrigation water the subdivision is using and when it is using it is essential for good water management. It is a key factor in: (a) knowing how much water to order from the weir; (b) avoiding having the Association fined for unlawfully using more water than we have ordered; and (c) for ensuring that Carmichael subdivision is not engaged in "water rustling" through unlawful diversion of water owned by our neighbor, Boxwood Ranch. It is also essential for planning a well-designed watering schedule for the subdivision. The watering schedule is important because it serves two ends: (*i*) efficiently using the water we have available; and (*ii*) avoiding unlawful excess use of water, including unlawful tapping into Boxwood Ranch's water. A practical watering schedule is: (*a*) one that the great majority of homeowners will comply with; and (*b*) one that can have compliance with it monitored and enforced.

In 2015 and 2016 the water management policy in Carmichael subdivision relied on having homeowners assigned to one of two alternate-day watering rotations: the Monday-Wednesday-Friday (MWF) rotation and the Tuesday-Thursday-Saturday (TTS) rotation. Within the constraints imposed by these rotations, homeowners were free to choose the time or times of day when they water and the length of their sprinkler station watering times. On the whole, homeowners behaved responsibly under this system with a measured compliance rate of better than 75%. The other 25% were subject to the Association's enforcement measures, which range from simple notification for unintended violations up to fines of $25 per day for willful noncompliance. The principal drawback of this scheduling plan is waste of water discharged unused on Sundays. In 2016 this waste amounted to roughly 11% of our total water order.

The goals of Carmichael's water management policies are: to ensure the Association complies with Idaho water laws and regulations; to provide enough irrigation water for healthy and attractive lawns and common areas within the limits of our allocated water supply; and to reserve enough stored water at the end of the irrigation season to tide the subdivision over in case of drought conditions the next summer or for multiple summers in row. The Association's Board ***has no other goals*** for its water management than these ***nor should it ever establish any additional goals*** superfluous to these three objectives.

In 2016 the Board instigated for the first time a system of inspections of Carmichael's irrigation system with collection of data on how and when Carmichael uses its irrigation water. Data collected through this inspection has revealed that between 74% and 86% of Carmichael households elect to water in the evening hours between 9:00 PM and 8:00 AM the next morning. Because there were two rotations, this means 37% to 43% of Carmichael residents water during that interval each rotation. The interval is therefore called the High Usage Period or **HUP**. At the upper end of this range, Carmichael's water usage is just within the limitations imposed by the constraints mentioned above. Water usage during the HUP is the single most important quantity affecting the subdivision's water management system and our lawful compliance with Idaho's water rights laws and regulations.

This makes data collection for quantifying water usage during the HUP a very important inspection activity. During the 2016 irrigation season a reliable method for collecting this data was developed. This section describes that method and explains why it works.

Inspection of HUP water usage is carried out in the morning starting at about 20 to 30 minutes before sunrise (civil twilight, see pg. 48). This timing is dictated by nature of the collectible data. It is not possible to hide watering activities in the subdivision. There are three key signs an inspector can look for to determine how many residences have watered during the HUP. These are: the presence of wet sidewalks (WSW); the presence of water puddles in the gutters (P); and the observation of sprinklers actually running (A). The timing of the morning HUP inspection is based on two things: (a) there must be enough early morning light for the inspector to be able to see these signs; and (b) the inspection must be carried out before the sun has time to evaporate WSW indicators. A typical HUP inspection takes about 20 to 30 minutes to carry out. Its purpose is data collection. *It is not part of water schedule enforcement*.

Daily count data is prone to random variations for a number of reasons. This means that reliable data on water usage can only be obtained using statistical methods. The Carmichael method is the following.

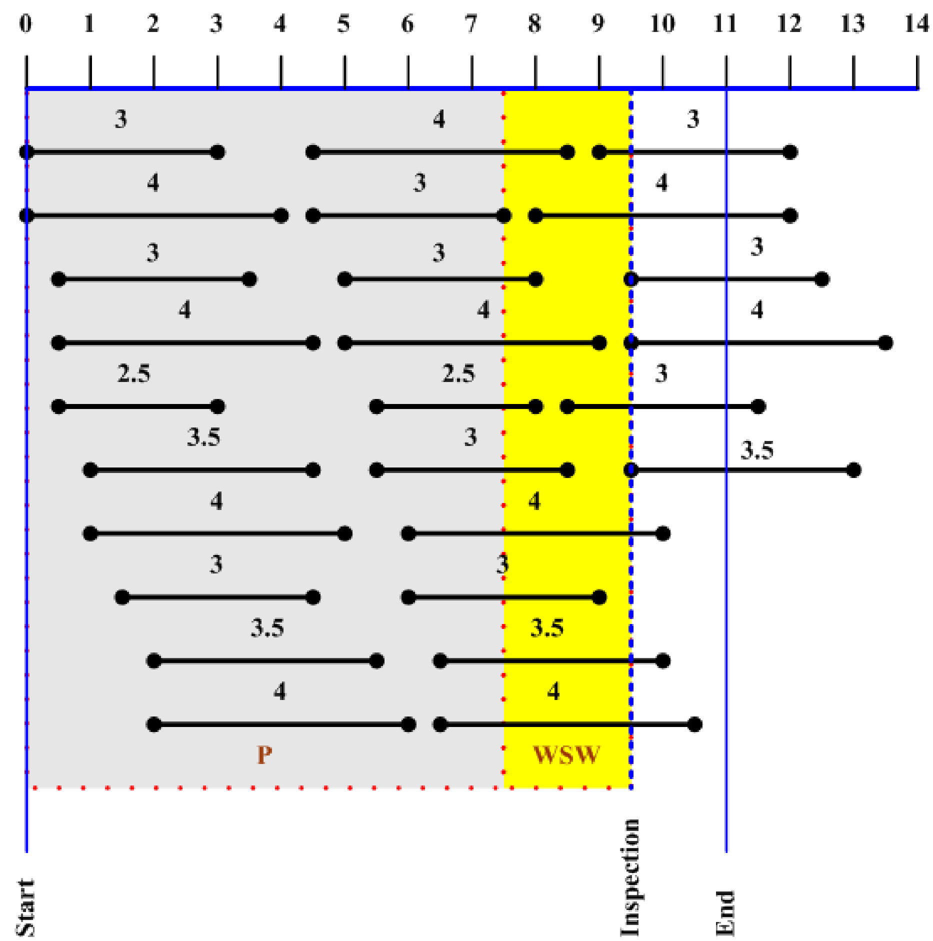


Figure 9: Illustration of a morning HUP inspection and data collection. Heavy black lines denote the watering activity of residences. The numbers above these lines are the total watering time these residences individually use during the HUP. The shaded area marked P is the interval during the HUP when gutter puddles (P) are left as evidence of the activity. The yellow area marked WSW is the interval during the HUP when wet sidewalks are left as evidence. The unshaded area is the point where active waterers (A) are observable. The start times for residential watering are staggered to provide a realistic picture of how residential irrigation activity actually happens. This example contains 26 residential waterers using total watering durations that provide a good representation of the distribution of watering in the subdivision.

The Carmichael method is best explained with the aid of an example. Figure 9 is an illustrative example of how the method works. The duration of Carmichael's HUP is approximately 11 hours (from 9 PM to 8 AM). However, it is necessary to carry out the inspection roughly a hour and a half before the end of the HUP. This is because during a Boise summer waiting until 8 AM to conduct the inspection means that some of the visible signs of watering activity will have vanished by the time the inspection is undertaken. The method is designed to work based on a *scientific sampling* of the actual usage. Statistical methods are then used to infer what the overall HUP watering activity is. To understand this method it is necessary to understand the properties of the WSW, P, and A observables.

'A' waterers are the most obvious because the inspector actually sees sprinklers in operation. In practice these are only observable when stations in the front lawn area are running. A residence can still be running its backyard sprinklers when the inspector drives past, but if this is so then there will be wet sidewalks and very fresh gutter puddles, and the residence will still be included in the inspection count. The length of time 'A' zones have been watering is uncertain. An 'A' zone might or might not have had time to affect pond Δ. *Total usage* count is P + WSW + A = N_{res}, the number of observed residences watering during the HUP. Uncertainty in A and WSW watering times is what makes W_{eff} an upper bound formula for Carmichael water consumption instead of an exact measurement of this consumption.

During the development of the Carmichael method, experiments were done to ascertain how long sidewalks stay wet after a sprinkler station stops running. This is, of course, a function of nighttime temperature, humidity, and wind factors. It was found that even during the hottest parts of the Boise summer, WSW evidence is still visible for **two hours** after the sprinkler station turns off. In the cooler part of the season they persist for over three hours. There are observable differences in "how wet" a wet sidewalk is at the time of inspection. These differences depend on how long the sprinklers have been off. It is convenient to classify how wet a sidewalk is in terms of three qualitative descriptions. A WSW is "fresh" (or "wet") if there is a lot of water on the sidewalk and one would expect to leave wet tracks on dry pavement if he were to walk through it. A WSW is "damp" if the sidewalk is obviously wet but one would not leave very visible tracks on dry pavement if he were to walk through it. A WSW is "dried out" if the sidewalk is discolored (due to water) but one's shoes would not get significantly wet if he were to walk through it. Beyond this there is no visible sign remaining. Hence, one can speak of "wet-wet sidewalks," "damp-wet sidewalks," and "dry-wet sidewalks." For purposes of inspection it is sufficient to count all three cases as WSW. Making these finer distinctions is useful for purposes of analysis but the method does not require an inspector to record these differences. "Wet" wet sidewalks stay "wet" for only tens of minutes after the sprinkler turns off. "Damp" wet sidewalks remain damp for a much longer time – about an hour or more. "Dry" wet sidewalks persist for two hours even in the hottest part of the season. WSW observability is much shorter during the daytime (well under an hour).

Experimental observations were also made to determine how long gutter puddles remain visible. The most surprising outcome of these observations is that when watering is carried out at night, puddles can and do persist for **eleven hours or longer** except where streets are steeply sloped. The longer the elapsed time is, generally the smaller the puddle becomes, but it is still visible. There are a few exceptions to this, and all of these pertain to residences where the front gutter has a steep slope to it and the residence watered early in the HUP. These residences can be checked by using dirt in the gutter because earlier watering activity will turn this dirt into "mud pie" markers which persist and can then be counted.

There are some practical challenges in counting P data. The most significant of these is the fact that the streets of the subdivision do have slopes and water runs down the gutters to the drains. Therefore a gutter can be wet in front of a residence even if that residence has not watered. Learning how to distinguish between a true puddle and gutter runoff does require a bit of practice. The key is that simple gutter runoff tends to form as streams of more or less uniform width. Puddles will usually appear as "fat spots" in the gutter runoff and may be accompanied by damp curbs either immediately adjacent to them or a short distance upstream from the gutter runoff. P-counts and ΔE/Δt measurements are correlated.

It can be very difficult to tell which of two adjacent houses caused a puddle. However, the purpose of the inspection is to ascertain *how many* residences watered, not *which ones* watered. The HUP inspection is not a violations check. Its purpose is to assess how much water the subdivision used during the HUP *and that is all*. Ascertaining watering schedule violations is an entirely separate, very time consuming, and *independent* activity. It cannot be made part of the inspection count activity.

Another practical difficulty in P-count data occurs when there is a flowing stream of gutter runoff passing in front of two or more houses. A flowing stream might or might not indicate more than one waterer (whether A, WSW, or P category). As a practical rule of thumb, if there is an A or WSW waterer on the *uphill* slope of the gutter then a flowing stream is not counted as a puddle. Otherwise the flowing stream is presumed to contain a puddle. Flowing streams are observed during most inspections. There are always random errors in counting possible during an inspection. These are one source of variances in the counts from one time to the next within the same rotation. ΔE/Δt provides an important check on P-counts because it is directly related to water usage. What is important to keep in mind is that the ***average***

consumption is what is important for good water management. The Carmichael method is a statistical method and sources of count data error, when averaged, give results that sufficiently cancel out random variations in count data observed from day to day. *Systematic* count errors must be avoided however.

Next the statistics of how to ascertain average HUP water usage is explained. For this explanation refer to figure 9 above as you follow along with the discussion I now begin.

In the hypothetical example there are 26 houses watering during an HUP. Each house has a watering duration ranging from 2.5 hours (typical of a house that waters twice a day with shorter station watering times) to 4 hours (typical of a house on a larger lot with many sprinkler stations). The average watering duration for this population is T_p = 3.42 hours with a standard deviation of 0.5233 hours. The number of houses watering (number of active zones, Z_k) during each half-hour interval is graphed in figure 10. These numbers are determined by counting the number of simultaneous waterers shown in figure 9.

The number of active zones at any given time tells us the instantaneous demand for water at that time measured in terms of numbers of zones. The average taken over the duration of the HUP gives us the average demand during the HUP. This statistic, $\overline{W}$, implies a watering demand of 15 gallons per minute times $\overline{W}$. For this hypothetical example $\overline{W} = 7.273$ zones with a standard deviation of 1.882 zones. $\overline{W}$ is depicted in figure 10 by the solid blue line. In this example the inspection is carried out 9.5 hours into the HUP and $\overline{W}$ must be estimated from the data collected at inspection time. The average number of active zones from the start of the HUP until the time of inspection is 7.211 zones with a standard deviation of 1.988 zones. This is depicted in figure 10 by the dashed green line. As you can see, the inspection statistic is insignificantly different from the true average.

Referring to figure 9, the inspection count will find 6 A, 6 WSW, and 11 P waterers for a total of N_{res} = 23 waterers. 3 go active *after* the inspector passes by. This distribution of A, WSW, and P waterers is a good representation of the relative distribution of watering signs typically found in the 2016 Carmichael HUP inspections. This means the example is a good representation of the typical watering distributions characteristic of the Carmichael subdivision. The task for statistical analysis of the inspection data is to estimate from N_{res} the true amount of water demand during the HUP. This is done using an empirically estimated **duty cycle factor**, ***d***, such that $\overline{W} = N_{res} \cdot d$. Analysis of 2016 inspections showed $d \approx 1/3$.

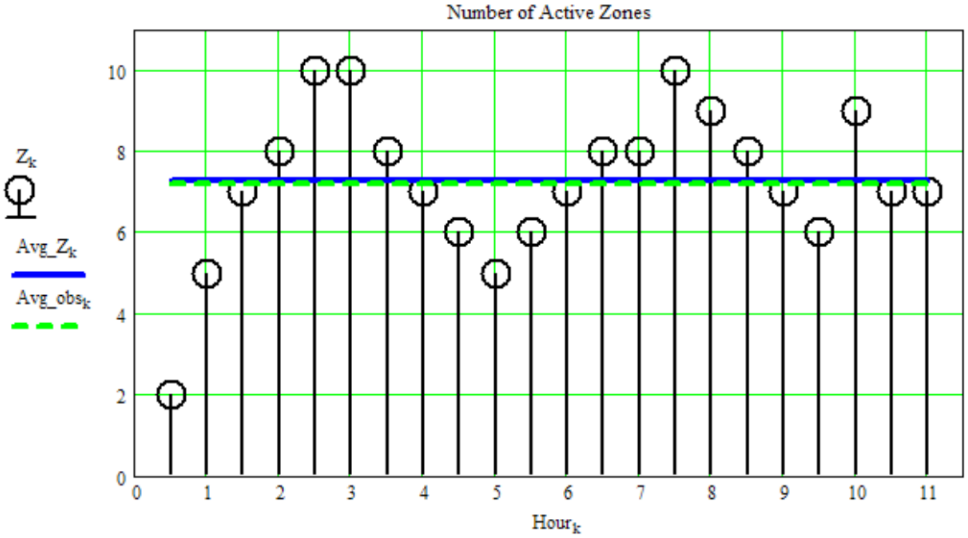


Figure 10: Number of active zones, Z_k, during each half-hour interval of the HUP (black data points). The blue line is the average number of active zones averaged over the entire HUP. The dashed green line is the average number of active zones averaged over the fraction of the HUP covered by the inspection.

What the factor *d* must do is compensate for the randomly staggered start times in the population of waterers and account for their randomly differing watering durations. You can think of *d* as way of modeling an "ideal" residence which represents the real population in terms of their average watering behavior. This is analogous to what the U.S. Census Bureau means when it says, "The average U.S. household in 2015 had 2.54 people." Obviously no real family has 0.54 children, but this statistic multiplied by the number of households in the U.S. gives us the population of the U.S. Like the average number of people in a household, *d* will tend to change over time as Carmichael residents sell their houses and new people move in or as summer weather conditions in Boise change over time due to long term climate trends. For example, in 1960 the "average U.S. household" had 3.33 people "in it" – implying the average family had 1.33 children. Statistics like *d* are the result of people's behaviors and preferences. This means the estimate *d* can be expected to need updating from time to time over the years. It also means that different watering rotations (e.g. MWF vs. TTS) can be expected to have slightly different *d* values because these populations consist of different people.

The duty cycle factor *d* is estimated statistically using data records collected during HUP inspections over a period of time. This data includes count data, $\Delta E/\Delta t$, observations of pond drop Δ, and knowledge of the supply of water coming to Carmichael from the weir at gate 178. Furthermore, *d* has *constraints* on its range of values. The principal constraint is that the quantity $d \cdot T$ (where $T = 11$ hours is the duration of the HUP) must return an estimated average residential watering time consistent with the known range of times typical residences need to water their lawns (3 to 4 hours). Because *d* must satisfy constraints on its value, this means its estimation must use a special statistical technique known as "linear programming," a method that must be performed by someone having technical expertise in it.

If *d* is perfectly estimated for our hypothetical example, its value would be $d = 0.314$, which is obtained by dividing the average number of active zones during the inspection period (= 7.211) by the $N_{res} = 23$ houses counted by the inspection. Note that this estimate of *d* implies an average watering duration for the population of $d \cdot T = 3.454$ hours. This compares to the actual population average in the example of $T_p = 3.42$ hours. Therefore the statistical estimate is within 1% of the actual value, which is a very good accuracy for statistical methods. Note, too, that $d \cdot 9.5$ hours (the number of hours covered by the inspection) is only 2.983 hours. This is because the inspection interval is less than the actual duration of the HUP and therefore *d* times the duration of the inspected hours is a biased underestimation of average residential watering durations. Note that 9.5/11 = 0.864 while 2.983/3.42 = 0.872 and the estimation is again accurate to within 1%.

When the duty cycle factor *d* was estimated for Carmichael subdivision from actual HUP inspection data, the results gave slightly different values of *d* for the MWF rotation and the TTS rotation. For the MWF rotation the estimated duty cycle factor is $d_{MWF} = 0.35$. For the TTS rotation the estimated duty cycle factor is $d_{TTS} = 0.32$. The average of the two is $0.335 \approx 1/3$.

Water Management, Excess Flow Rate, and the Raul St. Division Box (RDB)

The RDB is not a standard division box design. Its peculiar arrangement, by which water for the north field of Boxwood Ranch must first flow into the Carmichael cistern, creates a problem for best water management practices in the Carmichael subdivision. To make the most efficient use of allocated water, and to effect best water conservation practices during drought years, it is highly desirable that the capacity of Carmichael's irrigation pond be exploited to the greatest degree possible subject to avoiding "water rustling" from Boxwood Ranch's water supply and low-water pump trips. The design of the RDB, however, makes optimum water management impractical to achieve.

The reason for this lies in the physics of transporting water from the Carmichael cistern to the pond during the HUP. When water level in the pond drops, this increases the pressure difference between the CC and the pond. Consequently the flow of water from the CC to the pond increases as pond water level decreases and is limited only by the flow rate supplied to the CC from the main cistern (MC).

Let W_s denote the supply rate. W_s is determined by three factors: the weir setting at gate 178; the level of water in the Moore lateral ditch; and the amount of water Boxwood Ranch attempts to divert to the discharge cistern (DC) in order to irrigate its north field. There are two special cases which need to be considered by Carmichael's water management.

The simplest of the two cases occurs when BR suspends all of its irrigation activities. When that happens, the farmer changes his water order from the weir at gate 178 to zero. W_s then equals the sum of Carmichael's water order, W_o, plus a safety factor, W_{sf}, chosen by the ditch rider, i.e., $\boldsymbol{W_s = W_o + W_{sf}}$. The safety factor is at the sole discretion of the ditch rider and generally varies from one ditch rider to another. In 2016 a new ditch rider was assigned to the Moore lateral and he tended to set W_{sf} to about 10 miner's inches. The safety factor is supplied in order to provide margin for customer supplies in the face of variations in ditch water levels. Carmichael is only charged for our W_o. The ditch rider does not tell us what setting he is using at any given time unless we ask him. However, the water master can tell if the weir setting has been changed by measuring the height of the screw above the gate wheel at the weir.

Only when BR is not irrigating does Carmichael's water master have the liberty to control the subdivision's water management to make maximum efficient use of the pond's capacity through choice of W_o. Unfortunately, BR does not coordinate its irrigation decisions with Carmichael's. The consequence is that the water master is not able to take full advantage of the situation because of the way the RDB is designed. The cost to Carmichael is that W_o is made larger than Carmichael's actual demand requires, thereby reducing the amount of water Carmichael can store up for the next year.

BR continuously irrigates on the majority of days. This is the second special case and it makes water management significantly more difficult for Carmichael. The principal constraint placed on Carmichael's water management by this case is avoidance of "water rustling." With the existing RDB design, the system model and actual usage data from 2016 tell us W_o = 10 to 12 miner's inches over the course of the irrigation season is needed to avoid both water rustling and drawing the pond down by more than 3 feet during the HUP [see table on pg. 53]. These settings allow adequate pond refill in the morning after the HUP when Carmichael's usage drops. However, I estimate it would be possible to order 1 to 2 miner's inches less water *per day* if the RDB design was different.

In this second case, BR typically orders 40 miner's inches from the weir and a total safety factor of 10 miner's inches is typically employed by the ditch rider*. In this case it is typical to see overflow from the MC into the CC. BR usually flows only part of its 40 miner's inches through the BRC to its west and south fields. The farmer has control of how he divides his water between these fields and the north field by how much he widens or reduces the opening of his gate from the MC to the BRC. As little as a single turn of his gate wheel makes a dramatic difference in how much water spills over from the MC into the Carmichael cistern (CC) and the discharge cistern (DC). In the first 9 days of June 2016, discharge over the MC ranged from a low of y = 5/8 inch to a high of y = 2 ½ inches of water depth. Increasing the spillover affects how much water flows through the C-pipe because of changing head pressure in the MC as its water level rises or falls. [*From April to late June of 2016, the ditch rider tended to use a total weir setting of 65 miner's inches and argued that Carmichael ought to be ordering 15 miner's inches].

However, *all this variation can have very little effect on pond drop*. For the first 8 days of June the measured drop in the water level of the irrigation pond varied only from 0.66 ft. to 0.88 ft., a range of less than 3 inches. The explanation for this lack of variability in Δ is that with increasing water flow over the MC spillway, the head pressure rises in the CC and water flows at a higher rate to the pond, decreasing as pond Δ becomes smaller. The physics of water flow from the RDB to the pond is such that in effect the pond drop is *naturally regulated*. It is the effect of the system being able to draw water from the RDB at a rate in excess of Carmichael's water order. **Excess flow rate**, W_x, is defined as $W_x = W_{eff} - W_o$, where W_{eff} is the average HUP usage and W_o is Carmichael's water order. The calculated excess flow rates for the first 8 days of June (excluding Sunday) are shown in the table below. Three of these days slightly exceed Carmichael's water order but remain well within the safety factor. The other data points demonstrate that

Carmichael did not use up its own water order on those days. The relevant data from the HUP inspections carried out on those days is given in the following table.

Date (day)	W_x	WSW	P	A	CA
6/1 (Wed)	0.8	13	27	8	2
6/2 (Thur)	-2.6	10	22	11	2
6/3 (Fri)	1.1	22	18	8	2
6/4 (Sat)	1.2	12	29	11	2
6/6 (Mon)	-1.9	12	21	10	0
6/7 (Tue)	-1.8	6	30	12	2
6/8 (Wed)	-1.9	12	23	10	2
6/9 (Thur)	-4.1	10	19	11	2

W_x is expressed in miner's inches. The other columns are count data.

W_o was 12 miner's inches on these days.

The data shows 10 miner's inches was adequate when 5 miner's inches of safety factor against ditch water level variation is factored in.

These W_x values demonstrate there would be no "water rustling" at an order of 10 miner's inches. The Boxwood Ranch farmer did not express any concern about the overages when I discussed this with him. His opinion was that these amounts are within the range of variability of water flows in the Moore lateral and therefore he was not worried about it. In his view, the purpose of putting in safety factors at the weir is to deal with all the different sources of day to day variation in the supply of irrigation water.

These W_x numbers are based on calculated estimates for W_{eff} obtained after enough data was collected during the summer to validate and calibrate the irrigation model and establish valid statistics.

If Carmichael had reduced its water order below 10 miner's inches and the ditch rider's safety factor did not compensate for it, then every additional 1 miner's inch decrease in W_o would add a miner's inch of excess flow and at some point BR would be forced to raise *their* order at the weir to replace what was being lost to Carmichael. At this point, Carmichael's water order would cross the line and become an unlawful over-usage of water. This is what constrains the Carmichael water order to be no lower than some minimum amount (10 miner's inches in the case of the water demand in the first 8 days of June 2016).

Carmichael's actual water usage cannot be directly measured because the system lacks the necessary instrumentation to do this and the design of the RDB prevents the ditch rider from measuring the total inflow to the CC. The method for estimating Carmichael's actual usage is discussed on page 34.

Generally speaking, the present design of the RDB and the way it permits one water customer to affect the other one is not a good design. It creates water management problems for both customers, hinders good water conservation practices, and makes actual usage rate measurements by the ditch rider impossible. The system is being made to work presently *only* because of friendly relationships and close interactions between the ditch rider, the Carmichael water master and the Boxwood Ranch farmer. It can be anticipated that some day the Boxwood Ranch farmland will be sold to a developer and a subdivision will be built on it. When that day arrives the present RDB will become unworkable. It is my recommendation to future Boards that when a Boxwood Ranch subdivision is proposed, the Carmichael Homeowners' Association should petition the Boise Project (BP) and urgently demand a redesign of the division box subsystem with the objective of achieving operational independence for the two subdivisions. The present BP ditch rider concurs with this recommendation.

Lawn Maintenance and Watering Schedules

The covenants of the Carmichael Homeowners' Association require all homeowners to maintain a healthy and attractive lawn free of unsightly brown or yellow spots. The Association's water management policy is directed toward making it possible for them to do so with the available irrigation water.

Lawn care experts generally agree that an established lawn requires a coverage of one inch of water per week. This amount includes rain water although rain typically is limited to the spring and fall in the desert. Over-watering a lawn is an unhealthy practice because an excessive amount of water produces run off before the water can sink into the soil and promotes fungus growth. Runoff carries away soil nutrients and excessive watering tends to make grass develop short root systems rather than the deeper roots necessary for a healthy and robust lawn. According to the USDA soil survey, Carmichael subdivision is built on sloping silt loam soil, which means the soil is composed of roughly 40% silt, 40% sand, and 20% clay. It has medium permeability to water, and water requires about 45 to 90 minutes to percolate through it to a depth of one inch. When a large amount of water is applied to it in a short amount of time most of this water will not have time to penetrate very far into the soil before it runs off or evaporates.

The best tactic for lawn irrigation in this type of soil is to water in modest amounts about three days per week. It is better to water twice a day for shorter durations than once a day for a longer duration but many Carmichael homeowners are naive irrigators and choose to water once a day three days per week. About 10% of Carmichael homeowners are unskilled irrigators and over-water their lawns by watering every day. This minority comprises the watering schedule violators in the subdivision. Lawn care experts advise that a person who waters once a day should do so for around 30+ minutes for stations with pop-up spray sprinkler heads and around 45+ minutes for stations with pop-up rotating heads. During the hottest weather these times increase by about 30%. These watering durations are sufficient to lay down the necessary one inch of water per week with three watering days per week.

The relatively slow percolation rate of Carmichael's soil is the principal reason why a supermajority of Carmichael homeowners choose to water in the hours from evening to dawn (the high usage period). Nighttime low temperatures in Boise run from 20° to 35° cooler than the daytime high temperature and nighttime humidity runs from 3 to 6 times higher than daytime humidity. These factors plus the absence of direct sunlight at night mean there is less evaporation during the HUP and therefore water is able to soak deeper into the soil than it would if irrigation took place around the noon hour.

Most of the lawns and some parts of the common areas in the subdivision exhibit "hot spots." These are small patches of lawn where water percolates into the soil more slowly or runs off more than it does in the rest of the lawn. Hot spots are caused by such factors as inhomogeneity in the makeup of the soil, the amount of shade present, and differences in the slope of the lawn at different locations. Hot spots usually produce grass with short root systems and are characterized by development of yellow or brown spots in the lawn. They typically occupy only a small portion of the lawn area covered by their specific sprinkler station. As a general rule, it is an inefficient use of the subdivision's limited allocation of water to treat hot spots simply by increasing the amount of watering applied by the sprinkler station. For this reason, homeowners should be encouraged to readjust their sprinkler heads and/or treat hot spots using gardening hoses, portable sprinklers, and city water from their outside water taps.

A well designed watering schedule for the subdivision must take all of these factors into account. A homeowner likely will not be able to give a cogent technical explanation for why one watering schedule is better for his lawn than another, but every homeowner can see for himself if his watering schedule is producing a healthy and attractive lawn or not. If the Association's Board mandates a watering schedule that is at odds with the above irrigation factors, homeowners will not voluntarily follow the plan and the resulting widespread violations will make management of the subdivision's limited water resources next to impossible. A well designed watering schedule should take maximum advantage of the irrigation pond's capacity to provide a flow rate matching buffer between the inflowing supply of water from the RDB and its outgoing rates of consumption. This is subject to the constraint imposed by the need to avoid water rustling from Boxwood Ranch. Generally speaking, a good watering schedule should allow the individual homeowners a maximum degree of liberty in setting their own watering schedules subject only to: restrictions that are necessitated by the subdivision's water allocation; the capacity of the irrigation pond; and compliance with Idaho's water rights laws as these pertain to Boxwood Ranch. A watering schedule that provides the homeowners with flexibility for meeting their private requirements with as few necessary constraints as possible is one that will enlist the greatest degree of voluntary cooperation from the homeowners. An inflexible and authoritarian watering schedule is one designed only to teach the Board members how little real power the Board actually has under Idaho law. Generally speaking, the more detailed a watering schedule is, the less likely it will be that homeowners will actually follow it. A plan that a majority of homeowners refuse to follow is a plan for water management failure.

Hot Weather

Temperature and precipitation directly affect demand for irrigation activity. Boise area weather is described in terms of historical averages and by above or below normal conditions in specific months in specific years. Typically July and August are the hottest months with the lowest precipitation in Boise. However, actual irrigation demand is not based on historical averages but rather on actual conditions year by year. 2016 was an above-average summer for temperatures and below average for precipitation.

The Western Regional Climate Center collects and publishes historical temperature and precipitation data for the Boise area. Based on measurements taken at the Boise Air Terminal from 1940 to 2015, they compiled the average monthly high and low temperature and precipitation data shown in the following table. For comparison purposes, the table also shows temperature statistics used by AccuWeather.com.

Month	Avg. High Temperature	Avg. Low Temperature	Avg. Precipitation (inches)	AccuWeather High	AccuWeather Low
April	61.7	37.4	1.20	62	39
May	71.1	44.7	1.29	72	47
June	79.9	51.9	0.84	81	54
July	90.9	58.9	0.25	91	60
August	88.6	57.6	0.28	90	60
September	78.1	49.3	0.55	79	51
October	64.8	39.7	0.81	65	41

These are monthly averages and do not tell us the average temperatures recorded for each day of the month. Limited data on that is available from AccuWeather. AccuWeather history data covers only one year and differs from WRCC data by a few degrees. AccuWeather reports daily average temperatures tend to rise day by day over the month from April through July and then decline from August to October.

The 2016 irrigation season was hotter and drier than average. The following table provides data on the 2016 departures from the Western Regional Climate Center temperature and precipitation averages.

Month	Avg. High Temperature difference*	standard deviation	Avg. Low Temperature difference*	standard deviation	Actual Precipitation (inches)	Change (inches)*
April	+6.7	8.839	+4.6	4.687	0.69	-0.51
May	+1.4	8.936	+2.6	5.744	0.86	-0.43
June	+5.2	10.759	+3.2	7.758	0.22	-0.62
July	-0.90	7.328	+1.10	5.213	0.27	+0.02
August	+1.40	6.108	+2.40	1.872	0.00	-0.28
September	-1.50	8.080	+1.50	4.523	0.21	-0.34
October**	0.40	4.750	4.80	2.881	0.00	-0.81

* 2016 actual minus WRCC historical average ** October 1-6 only

Note that all but one of the standard deviations are larger than the average differences. This is because the average difference does not reflect extremes in temperature variations. Day to day extreme variations fall within about two standard deviations from the historical average values.

Homeowner reactions to weather exhibit a wide range of behaviors. Some homeowners are slow to notice any effects weather changes are having on their lawns. Their reactions to the weather tend to lag the actual changes by several days. Other homeowners appear to anticipate changes in their irrigation needs based on weather forecasts. These homeowners tend to alter their irrigation demands before the fact. Some homeowners appear to adopt a policy of extra watering "when needed" to keep up with hot weather without altering their basic lawn sprinkler settings. Day to day irrigation variation is large.

Observations of the conditions of lawns in the subdivision tend to imply that many homeowners do allow their lawns to dry out a little and alter their irrigation demands when they notice changes in the color of their grass (lawn color being a direct indicator of under-watering). Homeowner reaction overall is more or less unpredictable. The water master's best indicator of how Carmichael residents are actually reacting is the $\Delta E/\Delta t$ measurement at the pump house. A rise in $\Delta E/\Delta t$ indicates that the pumps are working harder, which in turn means more water is being demanded by individual irrigators. When changes in $\Delta E/\Delta t$ indicate the onset of a trend in water demand the water master should begin to consider whether or not a change in the subdivision's water order from gate 178 is appropriate.

Water Demand During the High Usage Period

Lack of instrumentation for measuring water flow rates and the confounding design of the Raul St. division box (RDB) combine to make precise measurements of Carmichael's actual water consumption rate impossible. The best that can presently be done is to *estimate* how much water is demanded from the weir using data obtained for the high usage period in combination with measurements of Δ and $\Delta E/\Delta t$. This is in part what is estimated using the formula for W_{eff}. The number of residential waterers by type (WSW, P and A) can be determined with sufficient accuracy by morning inspection counts. The number of common area zones, CA, is known because the water master has control of the settings for their sprinkler controllers. Pond drop Δ can be directly measured. W_{eff} is the difference between flow demand estimated from count data and flow from the pond in excess of its refill rate as ascertained from Δ.

Uncertainty in the real consumption is caused by uncertainty over how many of the 'A' and 'WSW' waterers have actually been running for a long enough time to have any effect on Δ. A typical residential zone (15 gal/min) watering for one hour draws 0.9 kgal during that time. This amount is not enough to produce a measureable change in pond water level. It is known for a fact that some 'A' waterers and some 'WSW' waterers counted during morning HUP inspection have not been watering long enough to affect the pond. It is also known for a fact that some have. 'Wet' WSW waterers, for example, are unlikely to affect pond drop but 'dry' WSW waterers are likely to have had an effect. Whether or not an 'A' waterer has been irrigating long enough to affect the pond depends on which sprinkler station is the one which is observed, what it's order in the station rotation is, and how long the station watering times for it and its preceding stations are. These are things that cannot be ascertained from inspection and, furthermore, are subject to variations when the homeowner changes his sprinkler controller settings.

For these reasons the best that inspection can accomplish is to establish **upper bounds** on Carmichael's actual consumption rate during the HUP. The general upper bound formula for W_{eff} is

$$\boldsymbol{W_{eff} = 1.667 \cdot N \cdot d - 1.852 \cdot \frac{19.3 \cdot \Delta + 2.47}{T}} \qquad \text{miner's inches (MI).}$$

An <u>absolute</u> upper bound is estimated by setting the number of watering zones N = WSW + P + A + CA. A <u>least</u> upper bound is estimated using N = P. A <u>best</u> (most realistic) upper bound estimate is obtained by setting N = WSW + P + CA. CA is the number of equivalent zones assigned to common areas. For zones CR, S-PK, and VH the rule of thumb is to equate each of these to 2 equivalent residential zones. The remaining five CA zones are equated to 1 equivalent residential zone. $d \approx 1/3$. The table below provides best (N = WSW + P + CA) and least (N = P) upper bound estimates for W_{eff} for the first three months of 2016. These two bounds in conjunction with $\Delta E/\Delta t$ measurements are used to synthesize final monthly usage estimates. Final usage estimates obtained for all months in 2016 are provided in the appendix.

Monthly Average Best and Least Upper Bounds on Water Consumption in 2016

		MWF Rotation				TTS Rotation	
Month		Least Upper (miner's in.)	Best Upper (miner's in.)	Month		Least Upper (miner's in.)	Best Upper (miner's in.)
May	mean	5.8	16.6	May	mean	5.9	14.9
	std. dev.		2.987		std. dev.		2.460
	no. obs.	9	9		no. obs.	10	10
June	mean	9.1	18.3	June	mean	7.8	14.9
	std. dev.		2.519		std. dev.		3.627
	no. obs.	11	11		no. obs.	12	12
July	mean	9.6	19.8	July	mean	9.2	16.7
	std. dev.		3.92		std. dev.		3.56
	no. obs.	12	12		no. obs.	13	13

As you can see, the spread between the least and best upper bounds is quite large. Observations made on days when BR was not irrigating prove that the best upper bound is always an overestimation. This is proved by the fact that it sometimes exceeded the total supply coming down from the weir at gate 178 as reported by the ditch rider. If the P-count is accurate the least upper bound is an underestimation. Actual usage lies between these two bounds. The method for estimating it is presented on pages 34-36. Based on qualitative observations of distributions of 'wet' vs. 'damp' and 'dry' WSW waterers, cases where 'A' waterers began irrigating at or shortly before the drive-by, and $\Delta E/\Delta t$ readings, this study finds that actual average water consumption is closer to the least upper bound than it is to the best upper bound.

W_{eff} is strongly influenced by conditions at the RDB. In particular, W_{eff} tended to be larger when there was a large flow from the MC into the CC accompanied by a large flow from the CC into the DC. Physically this is because under those conditions the flow from the CC to the pond is faster due to increased head pressure at the CC. This phenomenon is a consequence of the peculiar design of the RDB, which forces an excess flow to the pond under these conditions. RDB conditions, especially MC spill-over, are strongly affected by ditch water levels in the Moore lateral.

One can legitimately ask how much effect the estimated HUP duration of 11 hours (9:00 PM to 8:00 AM) has on the range of W_{eff} estimates. The beginning of the HUP was estimated from evening inspection data and incidental observations made at night from 10:00 PM to midnight that were not part of a formal inspection. Analysis of the rate of change in pond drop Δ as a function of the number of zones watering shows that the HUP duration can be no shorter than 8 hours, and a worst case factor analysis shows that this variation can reduce the upper bound estimates of W_{eff} by no more than about 2 miner's inches. This is within one standard deviation of W_{eff} statistics and therefore cannot be regarded as statistically significant.

Variability in Water Supply

As noted earlier, data collected during 2016 proves that even when the weir setting is fixed there are day to day variations in the actual flow coming into the RDB from the weir. Analysis indicates the nominal variation from the W_{178} setting is in the range of ± 3.5 miner's inches. It can be much more than this occasionally. Not all causes of this variability are known but some were identified during 2016.

One of them is upstream demand from the Moore lateral. On July 4th a new irrigator was added to the lateral upstream of gate 178. This irrigator uses pumps to draw water directly from the lateral, and his usage that day caused a drop of several inches in the level of water in the lateral. This caused a severe undersupply of water to the RDB (BR was not irrigating that day) which resulted in a pond drop Δ of 2.64 ft. by 6:18 AM. At 9:20 AM Δ was 3.08 ft. After discovering this during the morning inspection, the ditch rider was contacted and informed of the problem. He readjusted the weir to make up for the overnight shortage. The same thing apparently happened again the night of August 2nd-3rd.

A second known cause is obstruction of water flow down the lateral by flotsam that clogs up a pipe somewhere in the ditch. A severe instance of this happened on May 10, 2016. The obstruction reduced the flow from the weir by over 50% and resulted in a low-water pump trip. On June 7, 2016, some flotsam made it down from the weir to the RDB and partially obstructed flow through the C-pipe.

There is at least one other unconfirmed cause of reduced flow reaching the RDB when the weir setting is fixed. On June 28, 2016, an unexplained reduction in RDB inflow resulted in a 1.56 ft. drop in the pond level. There was no sign of any upstream flow problem in the Moore lateral. I speculate the cause was upstream usage causing a short term drop in ditch water level overnight followed by a recovery (pg. 41).

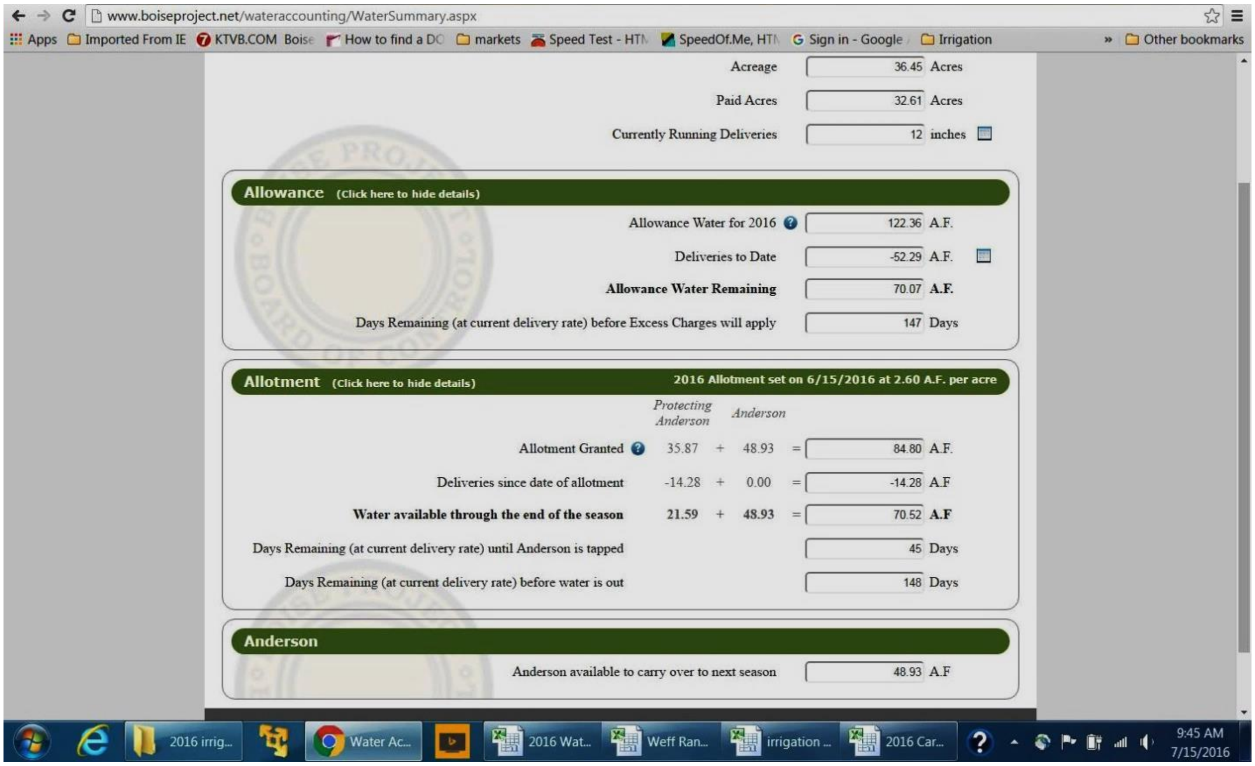
These incidents document that water supply to the RDB undergoes variations when the weir setting at gate 178 is unchanged. The existence of these variations demonstrate the need to make sure Carmichael's water order provides adequate margin for pond drops in order to avoid low-water pump trips.

One more thing the water master must always bear in mind is that even the nominal weir setting quoted by the ditch rider is an estimate. How accurate it is depends on the individual ditch rider and can vary depending on such factors as how busy he is on any given day, whether or not upstream ditch level variations have reached the weir at the time of the setting, how distracted he might be on any given day by personal and emotional factors, and how carefully he measures and states weir flow. The accuracy of the handheld mechanical tool he uses to measure W_{178} is not much better than about 10% to begin with. W_{178} is set by turning a wheel that raises or lowers the weir by means of a large bolt, and this is not a method with pinpoint accuracy. Ditch riders sometimes have a tendency to state weir settings in increments of 5 miner's inches. I had the opportunity to observe the weir setting process during the 2016 irrigation season. Although the ditch rider exercises due diligence in his work, he does not split hairs on how finely he makes the adjustment. I estimate that there is at best about ± 2 miner's inches of uncertainty in the weir setting at the time it is made. The water master should therefore regard the stated weir setting as a range variable, i.e., as $W_{178} \pm 2$ miner's inches. This consideration is especially important during times when Boxwood Ranch is not irrigating because at these times W_{178} is at its lowest setting (less than 20 miner's inches, including safety factor, instead of around 60-65 miner's inches).

Miscellaneous Considerations

The Carmichael Homeowners' Association pays for common area irrigation water from the New York Canal Irrigation District from homeowners' dues. Despite the fact that the Association is the party of record for the subdivision's irrigation rights, the irrigation district assesses *individuals* for their individual property's share of the irrigation water used by residences. Treasure Valley irrigation districts are notorious for not reminding people of unpaid irrigation district taxes and it is necessary for the water master to keep himself informed of the status of irrigation district payments in order to avoid having irrigation water unexpectedly cut off due to nonpayment of assessments by individuals. The Carmichael subdivision covers 36.45 acres, all of which is subject to irrigation district taxes. The Boise Project website http://www.boiseproject.net/wateraccounting/WaterSummary.aspx provides a complete list of who has and who hasn't paid their taxes. Unpaid acres subtract directly from the amount of water the subdivision is allocated. Responsible water management requires good record keeping by the water master, and this record keeping must include keeping account of the payment status of the New York Irrigation District's tax assessments for Carmichael's water allocation.

Another miscellaneous consideration is the total amount of carryover that can be accumulated at the end of the irrigation season. This amount is not unlimited. Rather, it is *capped* at nominally 1.5 AF/acre times the number of *paid* acres. In a nominal year this amounts to around 48 AF. The cap is because of the storage capacity of Anderson Ranch reservoir.



Acreage 36.45 Acres

Paid Acres 32.61 Acres

Currently Running Deliveries 12 inches

Allowance (Click here to hide details)

Allowance Water for 2016 122.36 A.F.

Deliveries to Date -52.29 A.F.

Allowance Water Remaining **70.07** **A.F.**

Days Remaining (at current delivery rate) before Excess Charges will apply 147 Days

Allotment (Click here to hide details) **2016 Allotment set on 6/15/2016 at 2.60 A.F. per acre**

	Protecting Anderson		*Anderson*			
Allotment Granted	35.87	+	48.93	=	84.80	A.F.
Deliveries since date of allotment	-14.28	+	0.00	=	-14.28	A.F
Water available through the end of the season	**21.59**	+	**48.93**	=	70.52	**A.F**
Days Remaining (at current delivery rate) until Anderson is tapped					45	Days
Days Remaining (at current delivery rate) before water is out					148	Days

Anderson

Anderson available to carry over to next season 48.93 A.F

Figure 11: Carmichael's irrigation water accounting page, July 15, 2016. See text below.

A third consideration that makes water management more challenging is the uncertainty of the precise duration of the irrigation season. A "normal" season is *nominally* 183 days from April 15 to October 15. A real season is often different and is primarily dictated by the weather. In drought years it might end sometime in August. Even in "normal" irrigation years, actual snowmelt and precipitation might cause the water authorities to end the season sometime in September. It turns out that no one ever really knows when the end of a "normal" irrigation season will be until very near the end of it. The water authorities who make this determination tend to take a "wait and see" approach to setting the date. For example, in 2016 the BP made an allotment of water (see section below) on June 15. However, even as of Sept. 1, no one – not BP, not the ditch rider, not the water authorities – knew the 2016 season would end Oct. 7th. In 2013 it ended September 5th. In 2014 it ended October 4th. In 2015 it ended October 6th.

Allotments

Every year the Boise Project issues an initial water ***allowance*** in April and reviews this allowance in mid-June. At that time they can issue an ***allotment*** of water, and when they do they usually lower the number of acre feet (AF) of water allotted to each water user. Factors such as April to June temperatures, precipitation, and volume of early snowmelt go into BP's June allotment.

2016 was regarded as a 'normal' irrigation year. Nonetheless, on June 15, 2016, BP issued an allotment revising our available water from an initial 3.75 AF/acre allowance to an allotment of 2.6 AF/acre (69% of the initial allowance). The reason was that spring and summer of 2016 were hotter and drier than normal with the consequence that early snow melt sent too much water too soon to the reservoirs.

The "water bookkeeping" for allotments is a little peculiar (figure 11).

The 2016 allotment reduced the number of watering days available (at 12 miner's inches per day) to Carmichael subdivision by only 11 days (241 vs. 252) because the allotment did not go into effect until June 15 *and was not applied retroactively*. (Had it been applied retroactively, it would have reduced the number of days of water supply to 175 days at 12 miner's inches; see table on pg. 16). However, this was not its most important effect. It also placed an additional constraint on Carmichael's water management by wiping out the stored water reserve from the 2015 irrigation season.

Under the initial allowance of 3.75 AF/acre, a water order of 12 miner's inches allowed 252 watering days (more than the length of the irrigation season). The allotment of 2.6 AF/acre reduced the available *total* supply of water to the 63 days prior to June 15 plus 178 days on and after June 15 (making a total of 241 days, which is also longer than a nominal irrigation season). The allotment was not applied retro-actively. It took effect on June 15th and was not applied to water consumed by Carmichael prior to this date. This demonstrates that the water authorities at the Boise Project did what they could to not *force* users to run out of water before the end of the season. The real cost to Carmichael was the loss of water reserves stored up in previous years. Carmichael and other water users had to make a tradeoff between how long they would let their 2016 irrigation season run vs. how much stored reserve they wanted to keep in the Anderson Ranch reservoir for carryover into 2017.

2016 was an El Niño year. In southwest Idaho it produced a slightly above average snowpack in the mountains during the winter and below average precipitation in Boise in the spring. An El Niño is frequently followed the next year by a La Niña, which typically has the opposite effect of El Niño. As of September 8th climatologists were forecasting a 55-60% probability that 2017 would *not* be a La Niña year (see pp. 38-41). The month before they had been predicting there would be. A strong 2017 La Niña would likely produce below-average snowpack in the winter and could result in a 2017 water allowance below the typical 3.75 AF per paid acre. Using the allowance number for the 2015 drought year as a guide, the water master recommended to Carmichael's Board a reserve 32 AF of stored water at Anderson Ranch for the 2017 season. In order to ensure a carryover reserve of 32 AF for 2017, it would be necessary to terminate the irrigation season early. The water master estimated this meant Carmichael's irrigation season had to be terminated on or before October 3rd, a 12 day shortening of the normal irrigation season. The Board declined to accept the water master's recommendation. The subdivision ended the 2016 season with a 31 AF reserve. This was the main effect of the 2016 allotment.

Allotment accounting is a little strange (figure 11). Water allotment is divided into two "buckets": (*i*) an "Anderson" bucket; and (*ii*) a "Protecting Anderson" bucket. The "Anderson" bucket is given by a constant determined by BP times the number of *paid* acres. In 2016 the "Anderson" bucket was 1.5 times the paid acres. As of July 15, we had 32.61 paid acres and the "Anderson" bucket was 48.93 AF.

The "Protecting Anderson" bucket is equal to the total allotment (2.60 times the number of paid acres) minus the "Anderson" bucket. This entry is a bit of a puzzle because BP does not say what it is they are protecting the Anderson Ranch reservoir from and the explanation of this figure they give on their web site is inadequate. As a practical matter, the number is the difference between the total allotment and the "Anderson" bucket. As of July 15, 2016, the "Protecting Anderson" number was 35.87 AF. 35.87 + 48.93 = 84.8 AF, which equaled 2.60 · 32.61 paid acres (rounded up).

What is most significant about the "Anderson" number is: *this number caps the maximum amount of stored reserve that can be kept in the Anderson Ranch reservoir at the end of the irrigation season*. The subdivision can draw *from* the "Anderson" bucket but it cannot *add to* this number. If the subdivision draws less than the "Protecting Anderson" amount, the leftover is simply lost.

Each year some number of Carmichael homeowners fail to pay their irrigation tax to the New York Irrigation District (NYID) by the due date of April 1. A few of them never pay it at all. When a home-owner pays his tax late, his previously unpaid acres are converted to paid acres and the subdivision's allocation is increased by the corresponding amount. This means both the "Anderson" and "Protecting Anderson" amounts increase. The http://www.boiseproject.net/wateraccounting/WaterSummary.aspx web page provides a list of all Carmichael taxpayers, how many acres they have, and whether or not they have paid their irrigation taxes. Therefore the water master and the Carmichael Board can always find out who has and who has not paid their taxes and how many acres their tax covers. Those homeowners who do not pay their irrigation tax cannot *lawfully* draw water from Carmichael's irrigation system. Therefore, it is the prerogative of the Board to deny them access to it and impose a fine on them for doing so *provided* that when the board publishes its watering rules in effect for the irrigation season it includes an explicit stipulation that homeowners who do not pay their tax are forbidden to use irrigation water. It only takes a $25 per day fine four days to exceed a homeowner's irrigation district tax.

Measuring Carmichael's Water Usage Rate

The system of dams, reservoirs, and canals in southwest Idaho was designed for agricultural irrigation. This primary application for the system influenced and determined everything about how the irrigation districts account and charge for irrigation water. The system was designed for water transport by gravity flow and for continuous irrigation without the use of pumps and pressurized systems. Boxwood Ranch is an example of the sort of irrigation the system was designed for. Many of the subdivisions in the city of Boise employ irrigation systems that are pressurized by pumps drawing directly from the canal or lateral that serves them, and these subdivisions operate in a manner not too much unlike the gravity-fed irrigation systems used by Boxwood Ranch and many other farms in Ada County. Most of the subdivisions do not have an irrigation pond and, because of this, are forced to try to mimic continuous irrigation flow by means of tight watering schedules requiring specific individual residences to water only on specific days during specific hours. In all these typical and almost-typical cases the accounting for actual water usage is relatively simple compared to the situation in Carmichael subdivision. The consumption of water by these subdivisions is more or less constant during the day and their usage of water is more or less the same as it is for farms like Boxwood Ranch ***if*** their water schedule is followed.

Carmichael's irrigation pond acts as a supply-and-demand balancing device and a temporary storage facility for irrigation water. In many ways the Carmichael irrigation system more closely resembles towns using old fashioned elevated water tanks to provide potable water and does not very much resemble agricultural irrigation. It provides the homeowners with much greater liberty to customize their lawn watering to suit the needs of their property within operating boundaries established by less strict and detailed watering schedules. On the whole this is a benefit to the homeowners and the Association.

The cost of this greater flexibility and benefit comes in the form of greater difficulty in determining how much water the subdivision is actually using. The system lacks instrumentation for measuring water flow, and this lack of instrumentation makes it necessary to *estimate* Carmichael's water usage using proven and accepted statistical methods. Methods for making such estimates range from the extremely crude and simple, to the time-consuming and difficult, to the theoretically ideal but impracticable.

The primary problem with crude and simple estimates is that their accuracy is poor and they can be challenged by ditch riders or by Boxwood Ranch if a dispute arises (such as the 2015 allegation that Carmichael was under-ordering water and "rustling" some of Boxwood Ranch's water). If these methods are challenged, it is impossible to prove their accuracy and challengers rightly regard them as nothing better than a mere opinion. Pragmatically, that *is* what they really are.

For example, the simplest and most crude way of estimating Carmichael's water demand is to take the total number of irrigating houses plus common area "equivalent lots" in the subdivision, divide it by the number of rotations in the watering schedule, divide this number into 6 sub-periods of 4 hours each (to reflect how long a residence waters), and multiply this by an average of 15 gallons per minute per watering zone. For Carmichael subdivision this equates to (116 residences + 45 CA lots*) ÷ 2 rotations ÷ 6 sub-periods × 15 gal/min = 201 gal/min = 22.4 miner's inches. This overestimates Carmichael's actual consumption by on the order of 10 to 12 miner's inches. Ordering this much water would reduce Carmichael's irrigation season to less than 155 days and leave no carryover storage for the next irrigation season. It is a bad estimate according to every practical consideration. [*Note: Carmichael has 10.25 acres of common area. The average lot size is 0.224 acres. The common area watering requirement is therefore equivalent to that of approximately 45.8 average lots.]

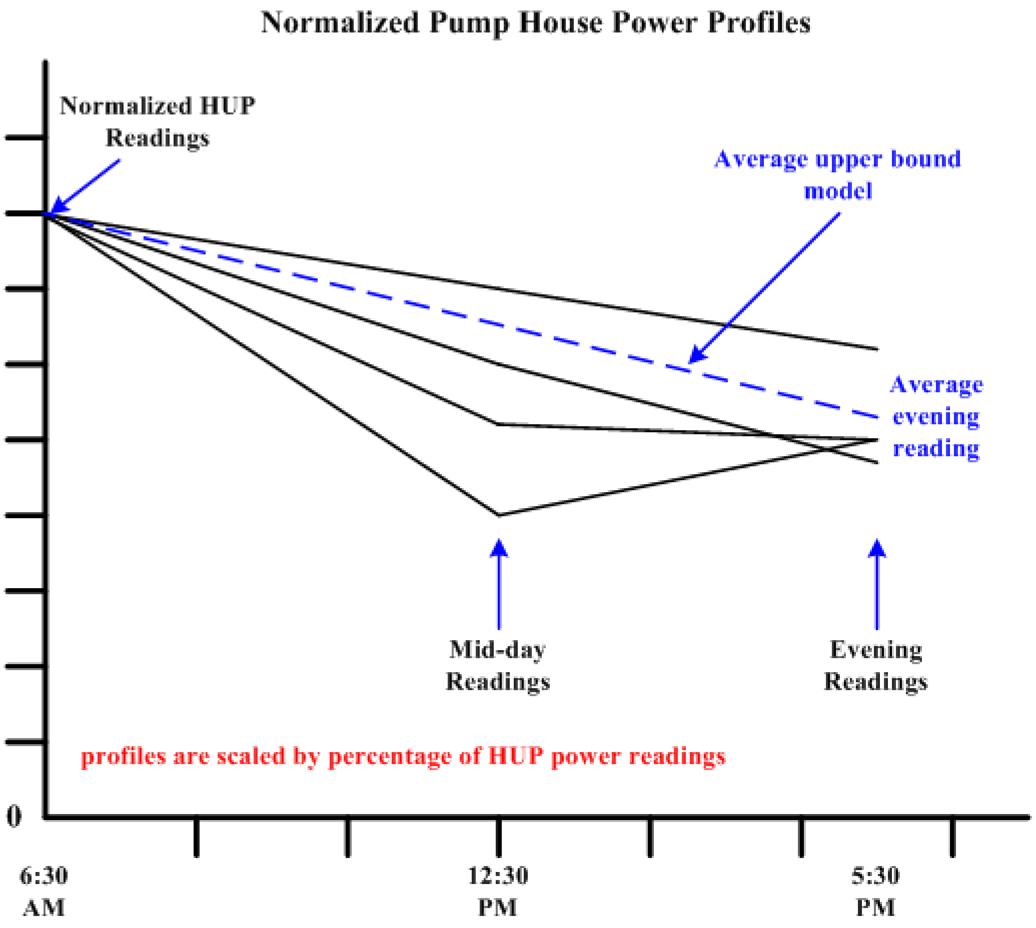


Figure 12: Observed pump house ΔE/Δt power profiles in 2016 normalized by HUP readings. See text.

The primary problem with accurate but time-consuming and technically difficult methods is that at some point they become infeasible to put into practice. This is either because no one is willing or able to undertake the time commitment required, the asset investment required is too expensive, or because no one with the necessary technical training to do them is available.

As it turns out, the greater accuracy obtainable in principle by such impractical methods is not much better than what can be obtained by simpler and practicable estimation methods. The estimation method recommended here makes a tradeoff between simplicity vs. absolute accuracy and gives a result that does not differ in any statistically meaningful way from what an expensive complex method would produce.

Direct estimation of water usage by means of inspections is practical only for the HUP part of the watering day. This is because during daylight hours key signs of water usage (gutter puddles and wet sidewalks) are eradicated too quickly by the sun (WSWs) or obscured because of earlier watering activity (gutter puddles). However, there is an *indirect* measure of watering activity that is available every hour of the day and requires only a few minutes to check. This is the ΔE/Δt power usage at the pump house explained on page 8. ΔE/Δt measures the rate of energy consumption by the pumps in the pump house. The pump system uses feedback control to regulate the head pressure of the sprinkler lines at the pump house. The pumps respond to drops in pressure in the lines to the subdivisions sprinkler systems (caused by active sprinkler operation) by running faster and, therefore, by using more power. When there is less watering activity, the pumps run slower, thereby using less power. When there is no watering activity both main pumps turn off and the jockey pump turns on to keep the sprinkler pipe system pressurized. Except during pump trips (when everything is off), the operation of the pumping action can be heard at the Clemens box behind the pump house.

Figure 12 illustrates observed ΔE/Δt vs. time of day power profiles recorded during the 2016 irrigation season. In order to make it easy to compare these profiles, the curves are normalized by scaling them relative to the ΔE/Δt HUP reading taken during early morning inspections. This is equivalent to making the HUP power reading represent 100% and the rest of the curves represent the power consumption as a percentage of HUP power. Actual ΔE/Δt curves (in kilowatts) shift up and down during the course of the irrigation season to reflect the changing water demands as the season progresses.

As shown in the figure, there were four different characteristic profiles observed in 2016. All of them demonstrated the highest level of ΔE/Δt occurred during the HUP. In most cases observed, the lowest level of ΔE/Δt occurred at midday (around 12:30 PM) and constituted a lowest-usage period. In these cases, water demand increased in the late afternoon leading up to the beginning of the next high usage period. In a small minority of cases, water demand by Carmichael residents continued throughout the day at monotonically decreasing levels. These cases illustrate the variability of water usage during the day due to individual homeowner actions as they take care of their own lawns' peculiar needs.

The average daily rate of water usage by the subdivision (in miner's inches) correlates to the average daily value of ΔE/Δt depicted in these curves. Close examination of the data shows ΔE/Δt curves are concave, which means the average daily value of ΔE/Δt is less than the average between ΔE/Δt measured for the HUP ($\Delta E/\Delta t_{HUP}$) and ΔE/Δt measured in the early evening ($\Delta E/\Delta t_{evening}$). Figure 12 obviously shows there is a significant degree of variability in the profiles (and, therefore, a significant degree of variability from day to day in water consumption rates). However, **all** of this variability can be upper bounded using a simple straight line curve depicted in figure 12 by the dashed blue "average upper bound model" curve. What this means is that the average daily ΔE/Δt over the course of many days is always less than or equal to the average value of this model curve. This average is given by the formula

$$\overline{\Delta E/\Delta t} \le 0.5 \cdot \left(\Delta E/\Delta t_{HUP} + \Delta E/\Delta t_{evening}\right)$$ (formula for average ΔE/Δt bound on a given day).

$\overline{\Delta E/\Delta t}$ is the average ΔE/Δt for one specific day. When this quantity is averaged over time, the data showed that the average ratio $\mathbf{p} = \boldsymbol{\overline{\Delta E/\Delta t} \div \Delta E/\Delta t_{HUP}}$ is remarkably constant. The ratio was 0.85 with a standard deviation of only 0.05 and is called the **p-factor**. This means the average daily pump power is less than or equal to 85% of the reading obtained at the HUP inspection. For example, if the HUP ΔE/Δt = 16 kW then, on the average, the daily average pump power is less than or equal to 13.6 kW if no unusual event (such as a pump trip) happens on that day.

$\overline{\Delta E/\Delta t}$ does not directly tell us how many miner's inches of water are being used. $\overline{\Delta E/\Delta t}$ must be *calibrated* to measured water consumption. Because the p-factor is remarkably constant, this turns out to be very simple to do using W_{eff} bound estimates computed by the formula

$$\boldsymbol{W_{eff} = 1.667 \cdot N \cdot d - 1.852 \cdot \frac{19.3\cdot\Delta+2.47}{T}}$$ miner's inches (MI).

It is known that actual W_{eff} lies between two bounding limits. The lower bound limit, W_{LB}, is found by setting N = P. The other bound limit, W_{MD}, is found by setting N = P + WSW + CA where CA is the number of equivalent common area zones watering during the HUP. The ***calibration estimate*** for W_{eff} is given by the formula

$$W_{CAL} = 0.5 \cdot (W_{LB} + W_{MD}) .$$

Because water usage is proportional to ΔE/Δt, and because the average daily $\overline{\Delta E/\Delta t}$ is given by the simple formula $p \cdot \Delta E/\Delta t_{HUP}$ (the ΔE/Δt reading taken during the morning HUP inspection), the estimated average daily water consumption by Carmichael subdivision is given by the formula

$W \le p \cdot W_{CAL}$ in miner's inches (average daily water consumption by Carmichael subdivision).

This is the ***close upper bound*** calculation upon which Carmichael's water order W_o is based. It is an upper bound because the average $\Delta E/\Delta t$ is based on the average upper bound model in figure 12.

In 2016 the hot weather season arrived at the beginning of June. In June the average daily water usage was 10.8 miner's inches (MI) with a standard deviation of 2.427 MI. In July the average was 11.5 MI with a standard deviation of 2.939 MI. The standard deviation is due to the general variability in the system brought about by such things as homeowners' fluctuations in their watering activity, changes in the level of ditch water in the Moore lateral, and the accompanying changes in actual delivery rate from the weir. To guard against occurrences of low-water pump trips these variations might cause while the system was being studied, its data collected, and its model verified, the water master kept Carmichael's order rate at 12 miner's inches throughout both these months. Future water masters can use the 2016 results to make their initial estimates of how much water to order (see table on pg. 53).

The empirically determined p-factor, $p \approx 0.85$, is the result of the watering habits of the people in Carmichael subdivision. Over time, as climate conditions shift and new people move into Carmichael subdivision, this factor of 0.85 can change. Indeed, it does show small month to month variations. Two indicators that this calibration factor might have shifted are: (a) an increase in the number of incidents of low-water pump trips; and (b) observation of a chronic increase in the amount of water discharging into the discharge cistern at the Raul division box when Boxwood Ranch is not irrigating. In case (a) the p-factor would be underestimating Carmichael's water consumption. In case (b) it would be overestimating it. In 2016 it was characterized daily using EXCEL™ to compute the numbers.

I note that there are a few other slightly more complicated models possible by which W can be measured. When I tested these models I found that they made no significant difference to the result presented here. The W modeling method presented in this handbook is the simplest one adequate to do the job of estimating the actual water consumption rate of Carmichael subdivision.

Common Area Watering and the Scheduling Challenge

There are several equivalent ways of determining an equitable distribution of how much of Carmichael subdivision's available supply of irrigation water should be dedicated to the subdivision's common areas. All of these are ultimately based on irrigation taxes paid by the homeowners out of their Association dues.

Carmichael subdivision occupies 36.45 acres. Of this, 10.25 acres are owned by the homeowners' Association and constitute the common areas of the subdivision. The remaining 26.2 acres are the private properties of the individual homeowners. Responsibility for maintenance and upkeep of the common areas, including irrigation, is the fiduciary responsibility of the homeowners' Association with governing authority for this vested in the homeowners' Board of Directors. By its authorized power of delegation, the Board delegates common area irrigation responsibility to the board appointed water master.

The equitable share of irrigation water dedicated to upkeep of the common areas is based on the ratio of common area to total acreage. This is because the irrigation taxes paid by the Association (out of its membership dues) are taxed at the same per-acre rate as the private properties in the subdivision. The common areas make up 28.1% of Carmichael subdivision. So, for example, of a normal water allowance of 3.75 AF per acre, the equitable portion of this for the common areas is $3.75 \cdot 10.25$ acres = 38.4 acre feet of irrigation allowance water allocated to the common areas.

In years when an irrigation allotment is issued by the Boise Project Board of Control (BP), this same arithmetic applies going forward from the allotment. For example, in 2016 the allotment going forward from June 15 was 2.60 acre feet per acre, and so the common area allotment was $2.60 \cdot 10.25 = 26.65$ AF.

Another way to figure the budget of irrigation water for the common areas is as a percentage of the water order W_o. The equitable share of the water order for the common areas is the percentage of common area acreage times W_o. For example, out of an order of 12 miner's inches the equitable daily allocation for the common areas is $0.281 \cdot 12 = 3.37$ miner's inches.

A third way to account for the common area share of irrigation water is by expressing the common area in units of "equivalent lots." There are 117 residential lots covering 26.2 acres in the Carmichael subdivision, making the average lot size 26.2/117 = 0.2239 acres. The common area occupies 10.25 acres or 10.25 acres/0.2239 acres per lot = 45.78 equivalent lots. An equitably planned watering schedule should be based on the number of residences using irrigation water plus an additional 45.78 common area equivalent lots. In 2016 there were 115 residences actively using the irrigation system and so planning for water scheduling should have been based on serving $160.78 \approx 161$ total equivalent lots.

A healthy lawn requires a covering of 1 inch of water per week. For the equivalent lot this equates to $(1 \div 12 \text{ ft./week}) \cdot (0.2239 \text{ acres}) = 0.01866$ AF/week. 161 equivalent lots implies the subdivision requires $0.01866 \cdot 161 = 3$ AF/week. The nominal irrigation season is 26 weeks long so this implies an allocation of $3 \cdot 26 = 78$ AF is required for *actual* irrigation out of the initial BP allowance. The remainder constitutes Carmichael's stored carryover for the next irrigation season. 78 AF converts to miner's inches of delivery as $78 \div 0.0396694 \approx 1967$ miner's inch days. The nominal irrigation season is 183 days so this implies an *average* water order of $W_o = 1967 \div 183 = 10.7$ miner's inches. The 2016 usage statistics tabulated on pg. 53 work out to an average W_o of 11 miner's inches over the course of the irrigation season. What these calculations show is that the homeowners' *gross* irrigation practices were remarkably close to optimum. What they do not establish is whether our water usage is being *equitably* distributed among the residences and common areas. Achieving equitable distribution is the scheduling challenge.

Tax Delinquencies

Irrigation tax delinquencies are an on-going problem for the Carmichael Homeowners' Association. Tax delinquents not only reduce the amounts of allowance and allotment water for the subdivision. They also use the subdivision's irrigation system, which means in effect that they are stealing irrigation water from the other residents and the common areas. The irrigation system has no physical means of shutting off irrigation water to individual residences and the Association has no power to directly collect irrigation taxes from delinquent homeowners.

For example, as of July 15th of 2016 Carmichael's total allotment was 84.8 AF based on 32.61 paid acres. There were 17 homeowners who failed to pay their irrigation district tax, which left 3.84 unpaid acres or $2.6 \cdot 3.84 = 9.98$ AF of water withheld by the Boise Project. As a direct consequence of this, the Carmichael subdivision had a shortfall of carryover water at the Anderson Ranch reservoir below the 32-to-34 acre feet this study deems to be a prudent minimum of reserve.

The issue of water theft by tax delinquents came to light in 2016 after the Boise Project issued its allotment on June 15th. On July 21, 2016, the Carmichael Board passed a new rule governing its water scheduling process. Beginning in the 2017 irrigation year, a notice will be included in the annual water schedule mailed to the homeowners stating that homeowners who do not pay their irrigation district tax in full *are prohibited from using the subdivision's irrigation system until the tax is paid in full*. The penalty for violation of this rule will be a $25 per day fine for infractions. The typical irrigation tax is less than $85, and so the new rule is intended to provide an effective incentive for homeowners to pay their taxes. The Board is authorized to take this action by Sections 6.07 (c) and 6.08 (j) of the Carmichael Master Agreement. Section 6.07 (c) gives the Board the power to levy fines for rule and covenant infractions. Section 6.08 (j) gives the Board the power to establish and promulgate Association rules. The tax status of every homeowner in the Carmichael subdivision can be viewed on-line at the Boise Project's water account web page, http://www.boiseproject.net/wateraccounting/WaterSummary.aspx .

Drought

Drought years and abnormally dry years are a recurring problem for Carmichael's water management.

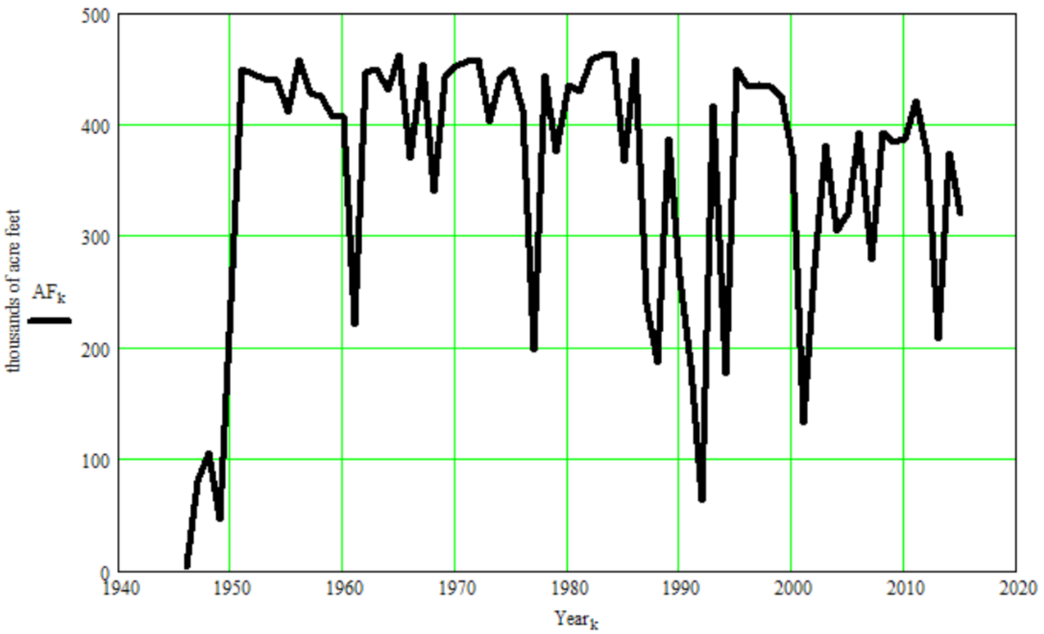
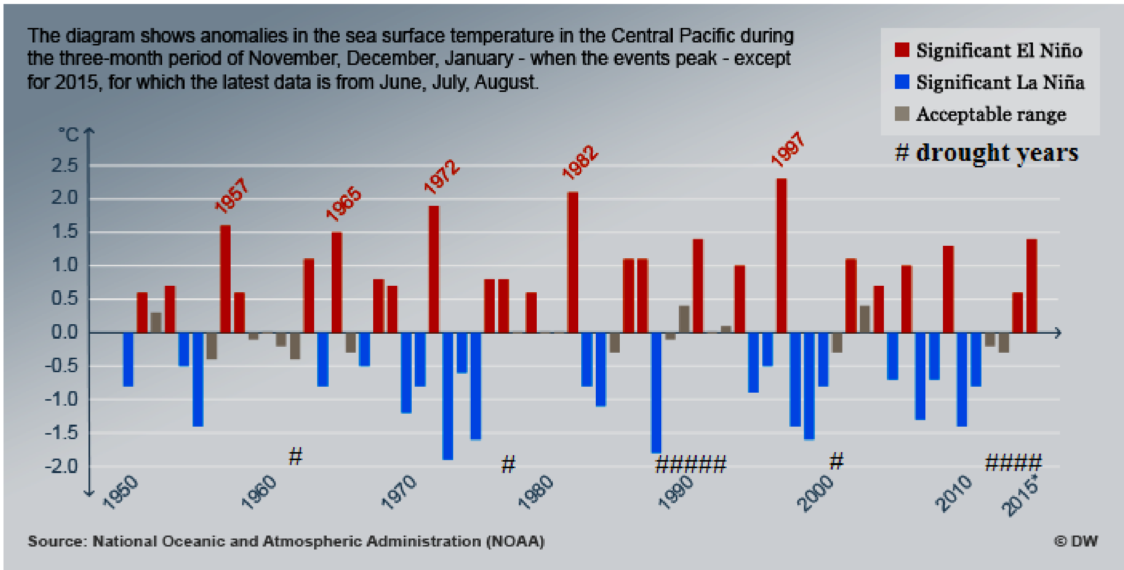


Figure 13: Historical end-of-July water storage at Anderson Ranch Reservoir in thousands of acre feet.


The diagram shows anomalies in the sea surface temperature in the Central Pacific during the three-month period of November, December, January - when the events peak - except for 2015, for which the latest data is from June, July, August.

Source: National Oceanic and Atmospheric Administration (NOAA)

© DW

Figure 14: Timeline of El Niño and La Niña events and Idaho drought years.

Allotments tend to be issued in dry years. Drought years bring major cutbacks. Since the mid-1980s a worrisome trend has been developing. From a practical management point of view, probably the best key indicator of seasonal drought and dryness conditions is provided by the historical record of water storage at the end of July at Anderson Ranch reservoir. The Anderson Ranch dam was completed in 1952 and ever since then as been the principal source of water for Boise area irrigation. Figure 13 provides the historical end-of-July data for water storage (in thousands of acre feet) in the Anderson Ranch reservoir.

The years 1961, 1977, 1987-1992, 2001, and 2012-2015 were all officially declared drought years in Idaho. The correlation between these drought years and end-of-July water storage at Anderson Ranch reservoir in figure 13 is very obvious. The figure 13 data also shows that since 1985 the end-of-July water storage has been trending downward. This is the worrisome trend, especially given Boise's rate of growth.

There is a notable correspondence between Idaho drought years and strong La Niña events. Figure 14 shows data from the National Oceanic and Atmospheric Administration identifying peak El Niño and La Niña events since 1950. I have annotated their graph to identify Idaho drought years. An Idaho drought does not always follow a strong La Niña, but they have 4 out of 8 times since the mid-1970s. By "strong" La Niña I mean a La Niña in which ocean temperature anomalies in figure 14 are colder than -1° C. In 2 of those 4 times the droughts have been multi-year droughts. As of Sept. 8, 2016, the National Weather Service was forecasting a 55-60% chance that the El Niño of 2016 would *not* be followed by a La Niña in 2017. They previously forecasted a weak La Niña event. If a strong La Niña develops in the fall and winter of 2016-17, the data indicates an Idaho drought in 2017 or 2018 has a 50% chance of occurring (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.html).

I have not been able to find any on-line historical records of Boise Project water allowances during drought years. The one data point I do have is the 2015 allowance of 1.7 AF/acre. This was only 45% of the normal 3.75 AF/acre allowance the subdivision receives in normal irrigation years. As Table I on page 16 shows, this allowance is inadequate to sustain irrigation for a full irrigation season even at a water order of 8 miner's inches. 2016 usage data collected and analyzed in this study show that 11 to 12 miner's inches is the order amount necessary to sustain the subdivision's hot weather demand for irrigation water. In 2015 the subdivision was able to irrigate for the full season with a water order of 9 miner's inches. No data was collected that year by which the subdivision's actual water usage can be determined. However, 2015 was the year when Boxwood Ranch complained about having to increase its water order and the ditch rider alleged that Carmichael had under-ordered its water and was tapping into Boxwood Ranch's water supply. Whether or not this is true cannot be proved (because no data was collected), but if the subdivision's water usage that year was similar to its usage in 2016, I would have to conclude from the 2016 data that there is a significant likelihood the allegation was true and that, at the minimum, Carmichael did tap into the ditch rider's safety factor. It should be noted that the allegations were not made known to Carmichael's Board during the 2015 irrigation season and the 2015 Carmichael water master's actions were taken in good faith and with the full concurrence of the Board.

In 2015 the Carmichael subdivision had an Anderson Ranch reservoir carryover of 1.1 AF/acre of stored water, and this reserve combined with the 2015 allowance was enough to sustain a shortened irrigation season ending October 10th at a 12 miner's inches order level. In 2015 Carmichael subdivision had 32 paid acres, so the carry-over reserve going into the 2015 irrigation season totaled 35 AF.

The drought of 2015 was less severe in Ada County than it was in some other Idaho counties (notably Owyhee County) where drought conditions were officially declared natural disasters. If the BP water allowance of 2015 is typical of drought years this strongly indicates that a policy of maintaining a minimum of 32 to 34 AF of carryover reserve at the Anderson Ranch reservoir in non-drought years is prudent. Given the occurrence of multiple-year droughts since 1989, even this amount is less than what would be needed for Carmichael to weather two successive years of drought. The maximum cap on water Carmichael can carry over at Anderson Ranch is 48 to 49 AF when tax delinquents are figured in.

A reserve of 24 AF (half of the maximum) plus an allowance of 1.7 AF/acre of new water in a drought year is only enough water to allow normal-year water usage until around the third week of September (assuming BP does not shorten the irrigation season to earlier than this date). The obvious conclusion from this is that in a drought year it will be necessary for Carmichael subdivision to operate under emergency conservation practices. Such was the case in 2013 when the Board asked homeowners to reduce the duration of their watering times, relaxed the covenant requirements by permitting front lawns to have "brown spots" due to under-watering, and asked homeowners reduce back yard watering. Such conservation measures are always very unpopular, but the reality is that there may be no way to avoid them, and in multiple-year drought conditions there *is* no way to avoid them. Drought exigencies require the water master and the Board to undertake very careful planning of watering schedule and watering duration restrictions in order to ameliorate the effect of a drought as much as possible. Contingency planning should begin before the end of current irrigation seasons and make use of what weather forecast predictions are available by late July regarding the outlook for the next winter's snowpack conditions. Late September and October are typically cooler periods and therefore the Board should consider and weigh the need for possibly shortening the present year's irrigation season in order to establish a carryover reserve if there appears to be a significant probability of drought the following year. If practically feasible it would be prudent to lay out contingency plans for dealing with two successive drought years. For multiple-year droughts longer than this, it is unlikely that any plan could entirely cope with such an exigency.

Planners must and should bear in mind that percentage decreases in water at the reservoirs do not translate one-to-one to percentage decreases in water allowances. What I mean by this is that a 10% decrease in water at the Anderson Ranch reservoir does not mean Carmichael's allowance decrease will also be 10%. *It will be a higher percentage than this*. This is because the Idaho Constitution (Article XV) mandates a prioritization of water appropriations "when the waters of any natural stream are not sufficient for the service of all those desiring to use the same." The constitutional priority goes: (a) those using the water for domestic purposes (subject to such limitations as may be prescribed by law); (b) those using water for agricultural purposes; (c) those using water for manufacturing purposes. Organized mining districts, where they exist, are sandwiched between (a) and (b). Under Idaho law, lawn irrigation is not recognized as a "domestic purpose" and so non-potable irrigation water for lawn maintenance is at the bottom of the priority list for the Treasure Valley's irrigation districts. Hence in 2015 Carmichael's water allowance was cut by 55%, an amount that greatly exceeded the water shortfall in the reservoirs.

The Dynamical Ditch

Unless you are a ditch rider or the Carmichael water master, you probably won't find the Moore lateral ditch to be very exciting. But if you are the Carmichael water master then sooner or later the ditch does get pretty interesting.

When you go down and look at the ditch the impression you will likely have is one of a placid waterway where nothing notable happens. Water flows slowly and almost silently in its shallow channel. The most noise heard there is produced at gate 178 as water drops down into the weir diversion area. In the ditch upstream of gate 178 water flows with barely a few ripples in its surface. The most notable thing about it is the amount of flotsam that collects on the upstream side of the pipe, where it passes under the pathway south of Valley Heights Drive, and at the entrance to gate 178.

In actuality the ditch is a very dynamic waterway. It appears unchanging and placid only because the changes in water level that it undergoes are impulsive events taking place over tens of minutes separated by intervals of from hours to days. Unless you are there when one of these unpredictable impulsive events occurs, you won't see it happen. There can even be two successive events, separated by hours, that cause large drops in ditch water level followed by large rises that cancel out the drops – leaving no visible clues in the ditch that they ever happened. The clues that they did happen show up at the RDB and at the irrigation pond. They appear as unexpectedly large drops in water level in the pond and the CC.

There are two principal causes of this dynamic ditch behavior. The first is change in the water level flowing in the New York Canal. From time to time the water authorities make changes in the flow of canal water and these changes affect the flow over the weir at the headgate where the Moore lateral begins. One of the ditch rider's jobs is to compensate for these changes by adjusting the headgate.

The other cause is water draw by the various customers who draw irrigation water from the Moore lateral. Among these customers, Carmichael subdivision is exceptional inasmuch as Carmichael is the only customer having a large manmade irrigation pond. Other customers tap directly into the ditch via

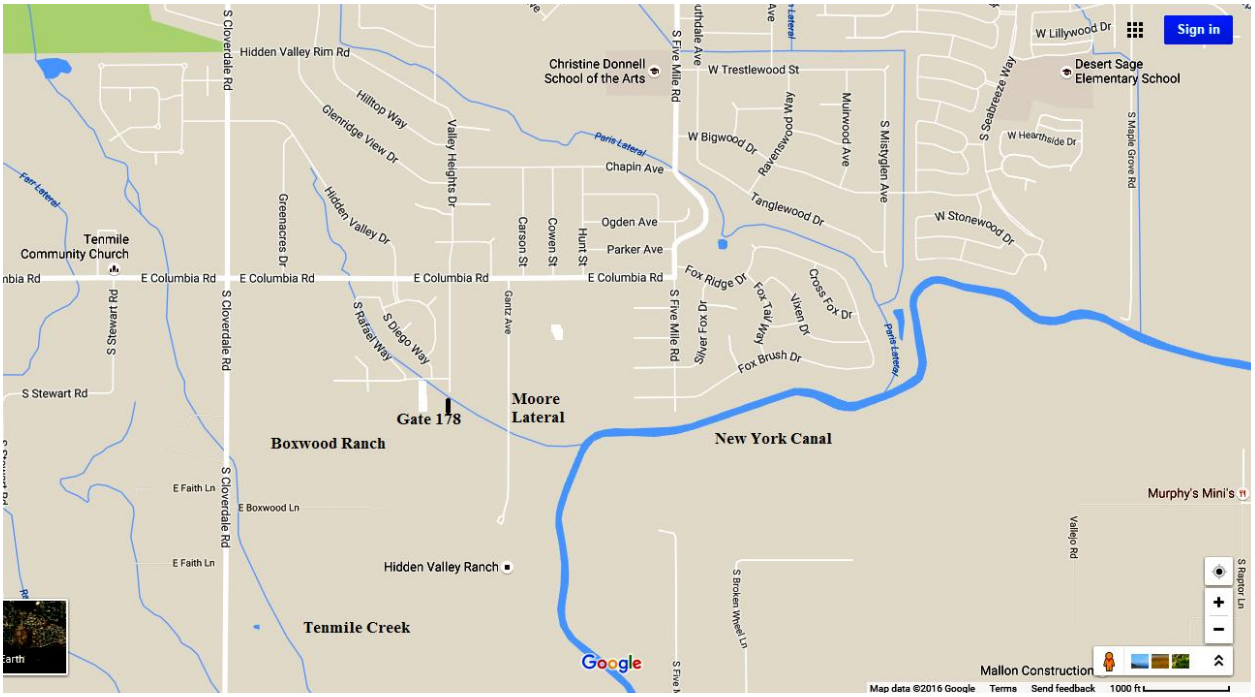


Figure 15: Map of the Moore Lateral

Figure 16: Aerial view of the area served by the Moore Lateral. West of the New York Canal the Moore Lateral is the only irrigation waterway. Tenmile Creek is a dry bed during the summer and does not carry irrigation water.

turnout gates.

Figures 15 and 16 are maps of the Moore lateral and its route from the New York Canal. Gate 178 is located roughly 2000 ft. (0.38 miles) from the headgate at the New York Canal. It is only one of several

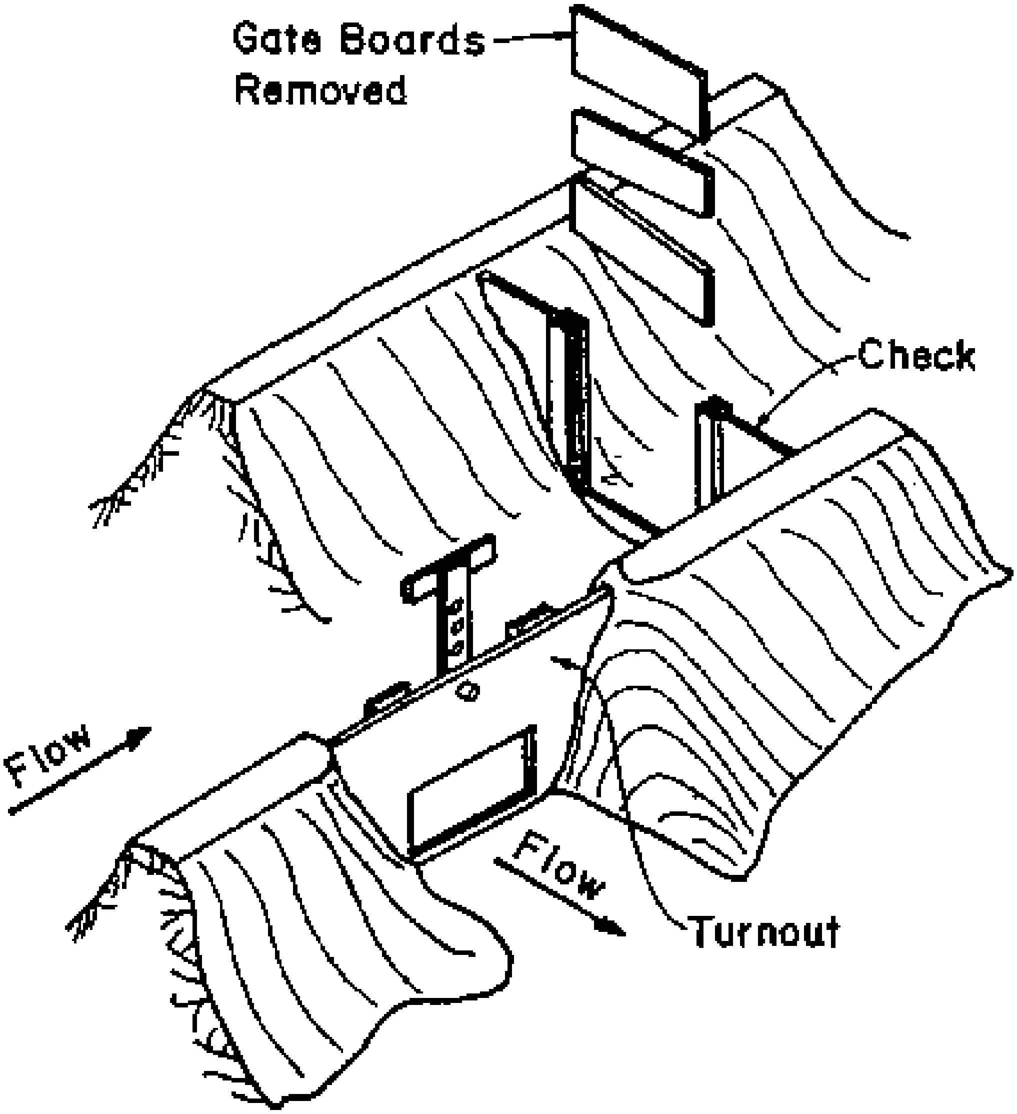


Figure 17: Sketch of irrigation ditch check structures and turnout gates. The main purpose of a check structure is to act as a sort of small dam for maintaining upstream water depth. Check structures are fitted with flashboards (called 'gate boards' in the figure) that act similarly to a weir. One such structure is located in the ditch between the pathway south of Valley Heights Dr. and gate 178. It has only a single flashboard in it. When the ditch is full the water level is 14.5 in. above the flashboard.

gates which tap into the ditch although gate 178 is one of the largest gate structures on the Moore. Turnout gates and check structures (figure 17) exist at various points along the Moore upstream and downstream from Carmichael subdivision.

The amount of water drawn upstream and downstream from gate 178 is changed by placing water orders with the Boise Project. The ditch rider opens or closes turnout gates according to the ordered amount. Individual customers can either access water by passive gravity flow (like Boxwood Ranch does) or by means of pumps and pump wells. In either case, changes in the water demand cause transient disturbances in water levels up and down the Moore lateral. The transient comes in the form of a water wave that travels as a 'pulse' of water. The pulse is either a crest or a trough of water when demand is abruptly reduced or increased. Figure 18 illustrates a water pulse produced in a laboratory setting.

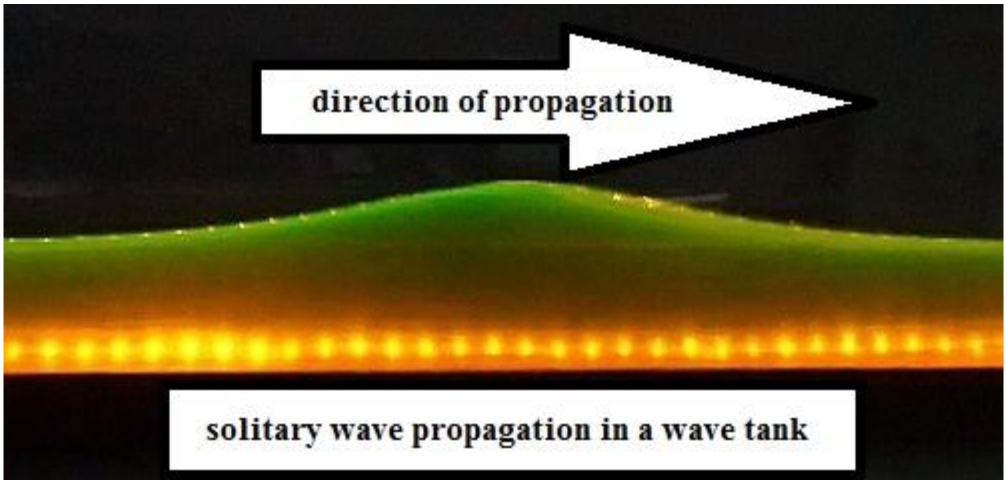


Figure 18: A solitary pulse wave propagating in a water channel in a laboratory experiment. Waves of this kind are usually called 'solitary waves' by most people or 'solitons' by scientists. The soliton phenomenon was first observed in 1834 in the Union Canal in Scotland by John Scott Russell.

According to the ditch rider, changes in ditch water level produced by a transient take a few hours to propagate from the New York Canal to gate 178. It is a slow process because it is a low energy event. In a real world structure like the Moore lateral there is no exact mathematical description of this phenomenon and equations that have been developed for understanding solitary wave propagation are accurate only in the more or less ideal structures built in laboratories for studying the phenomenon. Even these equations are complicated and hold meanings only for the trained scientists who use them.

Their effects can be seen at the RDB by measuring the water height going over the spillway between the main cistern and the Carmichael cistern. In one case, in the late morning of August 2nd of 2016, a 2 inch rise over the spillway was observed to happen over a half-hour interval from 10:00 AM to 10:30 AM. When a low water trough travels through the Moore lateral, the effect on pond drop during an HUP can be dramatic. During the August 1st-2nd HUP, the pond dropped overnight by 2.5 ft. even though water usage by Carmichael that night was modest (39 HUP waterers plus the Valley Heights common area). Typically this usage level would have produced a pond drop in the range of 0.4 to 0.9 ft. This event nearly drained the CC and uncovered the pipe from the CC to the pond.

The only way to quantitatively measure changes in the ditch water level is to use a dipstick to measure the number of inches of water flowing over the top of the flashboard between gate 178 and the pipe that goes under the pathway south of Valley Heights Dr. 2016 data on this is limited because this data was not being collected until August 3rd (in the aftermath of the August 2nd pond drop event). The data that was collected is statistically summarized in the appendix.

One consequence of these slow water dynamics is that it is possible to have two events occur overnight during the HUP which leave the ditch water level more or less unchanged during morning inspection from what it was during the previous evening inspection. However, even though the ditch water level returns to the previous evening's level, the effect on the pond and the Carmichael cistern can be dramatic. This is because the MC, the CC, and the pond take many more hours to recover from the drainage during the HUP. Generally speaking, when an inspection reveals evidence that the water height above the MC spillway is changing, the inspector should be alert to the possibility that a transient event may be happening in the ditch. These transients are responsible for some of the larger variations in pond water level and are large contributors to the standard deviation in water usage statistics.

Water Ordering, Seasonal Variations in W Estimation, and Good Judgment

The upper bound calculation W presented in this handbook is based on formulas I have determined to be robust throughout the irrigation season. By "robust" I mean that the formulas and methods can be used from April to October. The water master is called upon to make decisions about how much water to order. These decisions should be based *in part* on the quantitative data collected but not *in whole* on them. There is a natural temptation to "let the numbers speak for themselves" and ignore other factors in making these decisions. However, there is a pronounced standard deviation in the statistics of the watering sign measurements (WSW, P, and A) as well as in the HUP W_{eff} bound estimates (from which estimated upper bound daily usages and monthly averages are calculated). Because the bound estimates are just that – upper bound estimates – it is prudent to keep in mind the fact that the subdivision's real usage varies month by month in ways not entirely captured by upper bound formulas.

The amount by which the upper bound W *over*estimates water usage by the subdivision has "seasonal" variations. The irrigation season has three sub-seasons within it: a) April through May; b) June through August/early September; and c) September through October. Sub-seasons (a) and (c) are "cooler seasons"; sub-season (b) is the "hot season." Variations in water usage month by month are affected by temperature, humidity, and homeowner judgments regarding what changes to make to their sprinkler controller settings in response to their perceptions of how much water their lawns need. There is also a physical factor that affects the mathematics of calculating W. This is the time of day when dawn arrives – a physical factor that sets when morning inspection counts can be taken. Many commercial sprinkler controllers permit the homeowner to set his station start times in quarter hour increments (e.g. 6:00 or 6:15 or 6:30 or 6:45). When inspection times are pushed past quarter hour increments this can and does affect the distributions of WSW, P, and A observables. Changes in the distribution of these counts mathematically affect the upper bound W that is estimated. Specifically, changes in these distributions affect the calibration value W_{CAL}, which in turn affects $W = p \cdot W_{CAL}$. More specifically still, ignoring *qualitative* factors can lead to September upper bound estimates of W higher than the actual usage by on the order of 2 miner's inches. In this section I discuss the factors that contribute to this variation in W estimation. They are what makes a "let the numbers speak for themselves" approach to water ordering imprudent. The water master must remain cognizant of these physical and qualitative factors.

The water master should not ignore his common sense when making water ordering decisions, especially near the end of the irrigation season when decisions should be tempered by considerations of how much water can be carried over in the Anderson Ranch reservoir for the next season. This does not mean the statistics – WSW, P, and A counts; N_r averages; and $\Delta E/\Delta t$ statistics – can be ignored. There is sometimes a thin line between "common sense" and "wishful thinking" the water master must not cross. An important question therefore is: How should the water master balance the quantitative information he obtains from inspection data against his common sense knowledge that "the weather is getting hotter" or "the weather is getting cooler"?

It is obviously more preferable for the water master to be able to correctly *predict* how much water to order than it is for him to look back at the end of the month and realize he under- or over-ordered water from the weir. Under-ordering increases next year's water reserve at the risk of causing low water pump trips or unlawful siphoning of unpaid water. Over-ordering avoids low water pump trips but also sends water that could have been reserved for the next season flowing down the discharge ditch instead. Unfortunately, predicting sometimes has a lot in common with fortune telling. The difference lies in how one uses *all* the available data in making judgments about the water order when that data shows a lot of day-to-day variation (which is what the standard deviation statistic tells us).

The only truly instrumented data the water master has is the $\Delta E/\Delta t$ data. $\Delta E/\Delta t$ is calculated directly from cumulative energy consumption readings at the pump house power meter. The energy consumption is directly related to how much water the pumps pump out the subdivision sprinklers. It is therefore an immediate indicator of rising or falling water demand. Unfortunately, it also shows significant variation from one day to the next and so it is challenging to spot *trends* from this data alone. It must also be *calibrated* to water usage by the use of WSW, P, and A count data. When in doubt, $\Delta E/\Delta t$ is the most important "tipping factor" in making water order predictions. But that doesn't mean it is the *only* factor.

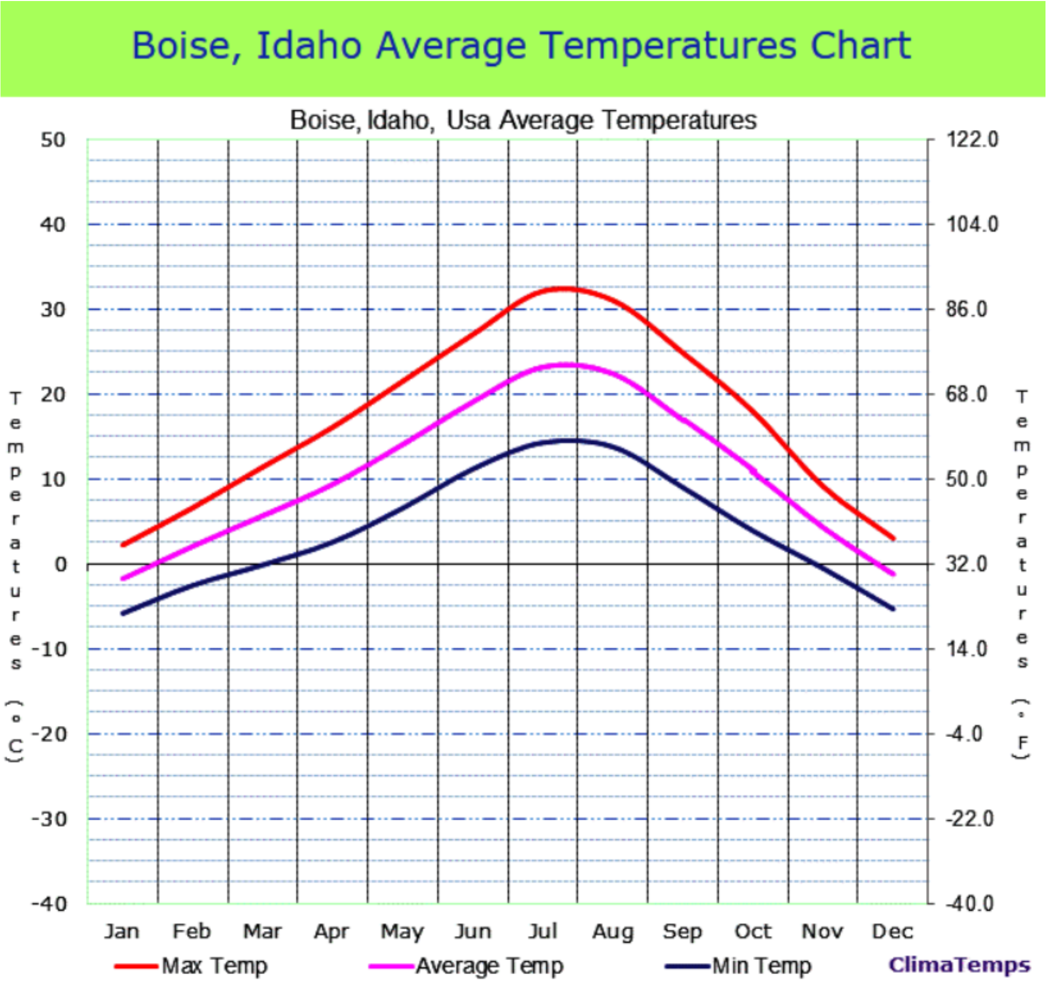
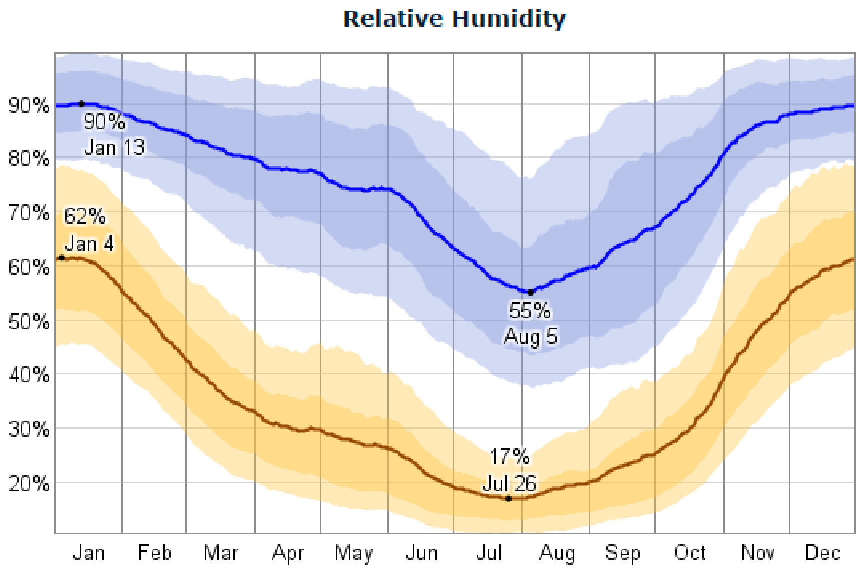


Figure 19: Average high, mean, and low temperatures in Boise published by ClimaTemps.com

WSW, P, A, and N_r (total HUP residential waterers count) are what statisticians call "count data." Count data has statistical characteristics that differ from "non-count" statistics such as average pond drop, temperature, amount of precipitation, and $\Delta E/\Delta t$. Count data distributions are characterized by what statisticians call a "Chi-squared distribution," and this kind of statistical distribution is very different from the "bell shaped curve" distribution often presumed in statistical pronouncements by the news media. This is one reason, for example, why political poll data jumps around a lot and can be misleading.

Why does this matter to us? The main consequence for the Carmichael water master is this: the first clue of a changing trend in water usage appears in the running average statistics of $\Delta E/\Delta t$. Count data (WSW, P, A, and N_r), in contrast, are slow to provide evidence of a developing trend. If count data and $\Delta E/\Delta t$ appear to show inconsistency with each other then attention must be paid to the more qualitative real-world factors that contribute to *causing* the physical effects that a statistic merely *monitors*.

The first and most obvious of these factors is temperature. Figure 19 exhibits the seasonal changes in high, mean, and low temperatures in Boise. What is especially interesting to notice is that *nighttime* temperatures in September more or less match those of May to early June whereas *daytime* temperatures in September match those of mid-May to mid-June. In other words, nighttime temperatures in September tend to start falling a week or two sooner than daytime temperatures do. The nighttime temperature is what affects percolation of water into the soil for HUP waterers. Lower temperatures imply less water evaporation at night and therefore promote more effective irrigation.


Relative Humidity

The average daily high (blue) and low (brown) relative humidity with percentile bands (inner bands from 25th to 75th percentile, outer bands from 10th to 90th percentile).

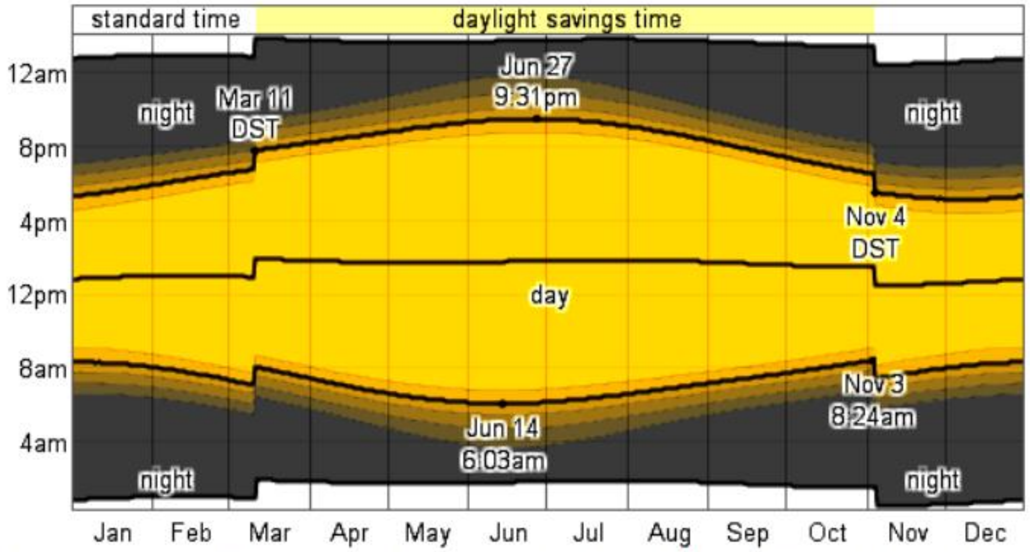
Figure 20: Average high and low humidity in Boise published by ClimaTemps.com

The second factor that affects irrigation by homeowners is humidity. Nighttime humidity in Boise is generally significantly higher than daytime humidity. Higher evening and nighttime humidity makes people feel colder than lower humidity does at the same temperature. This is why a desert is "chilly" at night. Higher humidity also reduces evaporation rates. Figure 20 illustrates how humidity in Boise changes over the year. Nighttime humidity (blue line) plummets in June and remains low through August. In September it begins to rise sharply. This, combined with dropping temperatures, tends to make people think their lawns require less watering in September than during July and August. Inspections carried out in 2016 revealed there is a significant fraction of Carmichael residents who do respond to changes in temperature and humidity by reducing the amount of lawn irrigation they do in early September. This behavioral effect was especially notable among HUP waterers in 2016. The change was demonstrated by a dramatic decline in HUP $\Delta E/\Delta t$ measurements during the first 9 days of September. When homeowners merely reduce their station watering times this will produce a reduction in $\Delta E/\Delta t$ but will not change the observed N_r counts – which means the same number of homeowners are merely using less water.

Curiously, this decline in irrigation activity among HUP waterers was not exhibited as much by those who watered in the afternoon and early evening. This was demonstrated by $\Delta E/\Delta t$ measurements for this group, which dropped by only half the HUP drop. There was a flattening of the $\Delta E/\Delta t$ profile during the course of the day. This meant that while HUP $\Delta E/\Delta t$ values declined by a large amount, the *average* $\Delta E/\Delta t$ for the day as a whole declined by a smaller amount. W_{CAL} is based on the latter, and this means that while the subdivision's water usage did begin declining at the beginning of September, the decline was less than what one would expect from looking at the HUP data alone. One plausible explanation for this behavioral phenomenon is that non-HUP waterers might be basing their judgments of their irrigation needs on their *daytime* perceptions of how hot or cold the weather is getting and then making (or not making) changes to their sprinkler controller settings after they get home from work.

There is a third physical factor that the water master must also consider. This one does not affect the behavior of irrigators in the subdivision but it does affect the mathematics of calculating the upper bound W. This factor is change in the hour when the sun rises in the morning. The reason this factor comes into play is because it affects when a morning HUP inspection can be carried out. The inspector necessarily must wait until there is enough light to see the watering signs, and this depends on when dawn arrives.

Daily Sunrise & Sunset with Twilight and Daylight Savings Time



The solar day over the course of the year 2012 . From bottom to top, the black lines are the previous solar midnight, sunrise, solar noon, sunset, and the next solar midnight. The day, twilights (solar, civil, nautical, and astronomical), and night are indicated by the color bands from yellow to gray. The transitions to and from daylight savings time are indicated by the "DST" labels.

Figure 21: Graph of when sunrise happens in Boise (www.timeanddate.com/sun/usa/boise)

Figure 21 illustrates when sunrise happens in Boise as a function of calendar date. As a practical matter, inspections can be made beginning in the civil twilight period, which begins around 30 minutes before the sun appears on the horizon (solar dawn) in Boise. The HUP inspection time interval T depends on the sunrise/civil twilight time and in this way sunrise time immediately affects the calculation of W_{eff}. It also affects the inspection counts WSW, P, and A. When a residence begins to water does not depend on when the sun rises but what the inspector counts does. As noted earlier, many popular commercial sprinkler controllers allow watering start times to begin at quarter-hour intervals. As inspections are advanced (April through mid-June) or delayed (mid-June through September/October) there are observable variations in P, WSW and A count data because of this. For example, a later inspection start time can convert some 'A' waterers into "wet" WSW waterers and some "dry" WSW waterers into P waterers. The tables below show the beginning- and end-of-month sunrise times in Boise during irrigation season and actual 2016 average inspection time intervals T (in hours). The table on pg. 49 summarizes the average waterers counts by rotation in 2016.

Boise Sunrise Times

Month	Sunrise is			
	Date	Time	Date	Time
April	15	7:01 AM	30	6:38 AM
May	1	6:36 AM	31	6:07 AM
June	1	6:06 AM	30	6:07 AM
July	1	6:08 AM	31	6:34 AM
Aug.	1	6:35 AM	31	7:08 AM
Sept.	1	7:09 AM	30	7:42 AM

2016 Average Inspection Time Intervals *T*

	Rotation		
Month*	MWF	TTS	
May	9.46	9.5	(time in hours)
June	9.39	9.43	
July	9.23	9.29	
Aug.	9.74	9.77	
Sept.	10.21	10.21	

*excluding Sunday

2016 Average Waterer Counts by Rotation

Month	Rotation							
	MWF				TTS			
	N_r	WSW	P	A	N_r	WSW	P	A
May	42.8	17.0	18.8	7.0	42.5	15.1	18.9	8.5
June	45.9	14.3	22.3	9.3	45.5	10.8	23.5	11.2
July	51.3	15.2	25.8	10.3	50.8	12.1	26.5	12.3
Aug.	51.1	15.9	25.2	10.0	50.3	12.3	27.9	10.1
Sept.	43.9	20.8	18.3	4.85	43.3	19.3	19.8	4.3

excluding Sunday

Several things in the table above are notable. First, the number of residential waterers N_r can be interpreted as a true indicator of the level of HUP watering activity. This is because N_r sums the counts for WSW, P, and A and is therefore immune to changes in the WSW, P, and A count data distributions. It has a weaker dependency on HUP inspection start time than the other count data do.

Second, the table data suggests there was a difference in the watering activities of the two rotations. The MWF rotation and the TTS rotation are comprised of different people and the two groups are not equal in number. There were 62 residences assigned to the MWF rotation but only 55 residences assigned to the TTS rotation. The actual difference in the number of residences watering during a rotation is not absolutely fixed by this because there was a small percentage (about 10%) of watering schedule cheaters in 2016. Hence N_r is comparable between the two rotations from May through September.

Third, factors of temperature, humidity, and later-arriving dawn make it likely for there to be an abrupt change in the WSW-P-A distribution observed in going from August into September. September can be a somewhat problematic month for the water master. Some Septembers in Boise are hot "Indian Summer" months. Others see a rapid cool down to autumn weather.

In 2016 a series of low pressure systems coming down from the Gulf of Alaska passed through Idaho pushing the jet stream to the south of Boise. This produced cooler than average Boise temperatures in September. Many Carmichael residents responded by reducing station watering times or ceasing twice-a-day irrigation. Station watering times for the common areas were also reduced by about 20%. These changes combined with the weather to make it more difficult to accurately assess the P-count during morning inspection because the combined effect was to produce more heavy gutter streams. This was particularly so on S. Diego Way, W. Carmichael Dr. from Diego to Katerina, and Rafael St. It became necessary for the inspector to be much more attentive to whether these streams were flowing down from wet WSW or A residences in order to avoid over-counting puddles. The gutter streams were characterized by deeper and broader stream flows and by the disappearance of the gaps between puddles that had been characteristically seen during August. These are *qualitative* changes, not *quantitative* ones.

In September of 2016 the onset of change in the WSW-P-A distribution came on rapidly. The change began Sept. 3rd and was complete by Sept. 8th. WSW counts increased significantly while A counts decreased significantly. This was largely due to the later sunrise (and therefore later inspection start time) in September compared to August. The inspector saw an increase in the number of "wet" WSW waterers in September compared to what he had been seeing in August, which implies conversion of what were formerly counted as 'A' waterers to 'WSW' waterers. With high probability these "new" WSW waterers were residences who were still actively watering in their back yards (where the inspector couldn't see their sprinkler activity). Gutter stream flow increased significantly. The average daily usage for the first 3 weeks of September declined to an upper bound of 11.4 MI with a standard deviation of 1.465 MI. If the increase in gutter stream flow had not been noticed an erroneous daily usage bound 1.5 to 2 MI higher would have been calculated because of puddle over-count.

The inspector observed reduced pond drops in September versus August, a higher volume of discharge from the Carmichael cistern into the discharge cistern, and slight pond overfilling. These observations implied a lower level of watering activity during the HUP. At the same time, both N_r and $\Delta E/\Delta t$ data demonstrated that actual HUP watering activity decreased in September compared to August. By the end of the first full week in September there was sufficient qualitative and quantitative data on hand to justify a reduction in Carmichael's water order from 12 MI to 11 MI. [Note: the water master delayed placing the new order in order to have time to analyze the theoretical implications of the new distribution of WSW-P-A waterer counts. After a sufficient amount of data had been collected it was determined that there was no change in the duty cycle factor d for either rotation and, therefore, the water usage upper bound estimate was still being validly computed despite the change in the WSW-P-A distribution].

On the morning of Sept. 21st the reduction in the water order, W_o, placed by the water master went into effect. The resetting of the weir occurred after the Sept. 21st HUP inspection had been completed. This means pond drop data from Sept. 1st to Sept. 21st can be directly compared with August pond drop data because the same water order was in place over both periods. The average pond drops from Sept. 1st to Sept. 21st were 0.73 ft. for the MWF rotation and 0.67 ft. for the TTS rotation. In comparison, the August average pond drops were 1.06 ft. and 1.07 ft., respectively, for the two rotations.

There is one final seasonal aspect the water master must be aware of. This happens near the end of the irrigation season. The Moore lateral serves a number of different customers. These customers either use up their water or finish with their irrigation activities at different times. This in turn affects the water level in the Moore lateral. As it happened, in September of 2016 Carmichael subdivision became the last active customer on the Moore lateral. This happened on September 23rd. All the other customers had used up all their water allocations by that day and their accesses to the Moore lateral were shut off by the ditch rider. He then reduced the flow from the New York Canal headgate and opened gate 178 as far as it could go because all water in the Moore was destined for Carmichael subdivision. These changes produced an overnight drop in the ditch level from just under 14 inches to 3 inches above the flashboard. The new flow rate reduced the amount of safety factor being supplied, a fact that appeared as a sudden drop in the inches of water flowing over the spillway between the MC and the CC. Spillover depth dropped overnight from around 2 inches to 0.5 inches and almost all the water flowing into the CC was supplied solely by the white C-pipe in the RDB. Because of the physics of how water is transported from the CC to the pond, this resulted in somewhat higher pond drops after Sept. 22nd although the water supply was still adequate to service Carmichael subdivision. My point here is that the water master should expect to see abrupt changes to the ditch and pond data as the irrigation season nears its end.

The lesson imparted by September 2016 is this: The inspector must be alert to spot changes occurring in the waterers distribution as well as qualitative changes in gutter stream flow and discharge from the CC into the DC. The Carmichael irrigation system exhibits large variations in count data that make a "numbers only" approach to assessing water usage and managing the water order overly conservative. By this I mean it can delay justifiable changes to the water order. This can lead to a waste of the subdivision's water supply by allowing water to flow "down the drain" into the discharge cistern that might have been saved for the next year's carryover in the Anderson Ranch reservoir. Attentiveness to qualitative factors and the exercise of good judgment are important for the best management of the Carmichael Subdivision irrigation system.

Appendix

2016 Irrigation System Statistics and Other Data

<u>High Usage Period (HUP) Statistics</u>

<u>May MWF Rotation</u>

$\Delta = 1.26$ with $s = 0.5876$ and $n = 9$
$N_r = 43.3$ with $s = 3.682$ and $n = 9$
$P = 18.8$ with $s = 2.819$ and $n = 9$
$T = 9.461$ with $s = 0.219$ and $n = 9$
$5.8 < W_{eff} < 16.6$ with $n = 9$

$N = 44.4$ with $s = 4.065$ and $n = 9$
$WSW = 17.0$ with $s = 3.741$ and $n = 9$
$A = 7.0$ with $s = 1.225$ and $n = 9$
$\Delta E/\Delta t = 13.7$ with $s = 1.934$ and $n = 9$
$d_{MWF} = 0.35$ $CA = N - N_r = 1.10$

<u>May TTS Rotation</u>

$\Delta = 0.97$ with $s = 0.481$ and $n = 10$
$N_r = 43.4$ with $s = 3.127$ and $n = 10$
$P = 18.9$ with $s = 4.954$ and $n = 10$
$T = 9.5$ with $s = 0.143$ and $n = 10$
$5.9 < W_{eff} < 14.9$ with $n = 10$

$N = 45.4$ with $s = 3.127$ and $n = 10$
$WSW = 15.1$ with $s = 4.383$ and $n = 10$
$A = 8.5$ with $s = 3.136$ and $n = 10$
$\Delta E/\Delta t = 14.05$ with $s = 1.212$ and $n = 10$
$d_{TTS} = 0.32$ $CA = N - N_r = 2.0$

<u>June MWF Rotation</u>

$\Delta = 0.893$ with $s = 0.1853$ and $n = 11$
$N_r = 45.5$ with $s = 3.240$ and $n = 11$
$P = 22.3$ with $s = 3.349$ and $n = 11$
$T = 9.39$ with $s = 0.1445$ and $n = 11$
$9.11 < W_{eff} < 18.3$ with $n = 11$

$N = 47.2$ with $s = 4.104$ and $n = 11$
$WSW = 14.3$ with $s = 3.101$ and $n = 11$
$A = 9.27$ with $s = 1.272$ and $n = 11$
$\Delta E/\Delta t = 16.9$ with $s = 2.315$ and $n = 11$
$d_{MWF} = 0.35$ $CA = N - N_r = 1.7$

<u>June TTS Rotation</u>

$\Delta = 1.12$ with $s = 0.6462$ and $n = 12$
$N_r = 45.4$ with $s = 4.337$ and $n = 12$
$P = 23.5$ with $s = 3.873$ and $n = 12$
$T = 9.43$ with $s = 0.0955$ and $n = 12$
$7.8 < W_{eff} < 14.9$ with $n = 12$

$N = 48.0$ with $s = 4.178$ and $n = 12$
$WSW = 10.8$ with $s = 3.769$ and $n = 12$
$A = 11.2$ with $s = 1.528$ and $n = 12$
$\Delta E/\Delta t = 16.8$ with $s = 1.857$ and $n = 12$
$d_{TTS} = 0.32$ $CA = N - N_r = 2.6$

<u>July MWF Rotation</u>

$\Delta = 1.21$ with $s = 0.6465$ and $n = 12$
$N_r = 51.3$ with $s = 5.941$ and $n = 12$
$P = 25.8$ with $s = 5.149$ and $n = 12$
$T = 9.23$ with $s = 0.6272$ and $n = 12$
$9.62 < W_{eff} < 19.8$ with $n = 12$

$N = 52.6$ with $s = 6.788$ and $n = 12$
$WSW = 15.2$ with $s = 3.512$ and $n = 12$
$A = 10.3$ with $s = 3.596$ and $n = 12$
$\Delta E/\Delta t = 19.3$ with $s = 2.387$ and $n = 12$
$d_{MWF} = 0.35$ $CA = 1.33$

<u>July TTS Rotation</u>

$\Delta = 1.17$ with $s = 0.672$ and $n = 13$
$N_r = 50.8$ with $s = 4.451$ and $n = 13$
$P = 26.5$ with $s = 3.119$ and $n = 13$
$T = 9.39$ with $s = 0.113$ and $n = 13$
$9.2 < W_{eff} < 16.7$ with $n = 13$

$N = 52.9$ with $s = 4.555$ and $n = 13$
$WSW = 12.1$ with $s = 2.234$ and $n = 13$
$A = 12.3$ with $s = 2.674$ and $n = 13$
$\Delta E/\Delta t = 18.3$ with $s = 1.725$ and $n = 13$
$d_{TTS} = 0.32$ $CA = 2.1$

<u>August MWF Rotation</u>

$\Delta = 1.06$ with $s = 0.6594$ and $n = 14$
$N_r = 51.1$ with $s = 6.145$ and $n = 14$
$P = 25.2$ with $s = 4.79$ and $n = 14$
$T = 9.74$ with $s = 0.1036$ and $n = 14$
$10.8 < W_{eff} < 19.96$ with $n = 14$

$N = 52.4$ with $s = 6.958$ and $n = 14$
$WSW = 15.9$ with $s = 1.46$ and $n = 14$
$A = 10.0$ with $s = 3.305$ and $n = 14$
$\Delta E/\Delta t = 19.8$ with $s = 2.3377$ and $n = 14$
$d_{MWF} = 0.35$ $CA = 1.36$

August TTS Rotation
$\Delta = 1.08$ with $s = 0.4798$ and $n = 13$ $N = 52.3$ with $s = 4.733$ and $n = 13$
$N_r = 50.3$ with $s = 4.733$ and $n = 13$ $WSW = 12.3$ with $s = 3.301$ and $n = 13$
$P = 27.9$ with $s = 3.427$ and $n = 13$ $A = 10.1$ with $s = 2.060$ and $n = 13$
$T = 9.77$ with $s = 0.1335$ and $n = 13$ $\Delta E/\Delta t = 17.9$ with $s = 1.6054$ and $n = 13$
$10.5 < W_{eff} < 18.1$ with $n = 13$ $d_{TTS} = 0.32$ $CA = 2.0$

September MWF Rotation
$\Delta = 0.85$ with $s = 0.390$ and $n = 13$ $N = 45.31$ with $s = 3.945$ and $n = 13$
$N_r = 43.9$ with $s = 3.752$ and $n = 13$ $WSW = 20.8$ with $s = 4.494$ and $n = 13$
$P = 18.3$ with $s = 3.326$ and $n = 13$ $A = 4.85$ with $s = 2.035$ and $n = 13$
$T = 10.21$ with $s = 0.261$ and $n = 13$ $\Delta E/\Delta t = 16.5$ with $s = 2.466$ and $n = 13$
$7.29 < W_{eff} < 20.2$ with $n = 13$ $d_{MWF} = 0.35$ $CA = N - N_r = 1.38$

September TTS Rotation
$\Delta = 0.98$ with $s = 0.906$ and $n = 12$ $N = 45.3$ with $s = 5.433$ and $n = 12$
$N_r = 43.3$ with $s = 5.433$ and $n = 12$ $WSW = 19.25$ with $s = 4.555$ and $n = 12$
$P = 19.8$ with $s = 3.324$ and $n = 12$ $A = 4.25$ with $s = 2.094$ and $n = 12$
$T = 10.21$ with $s = 0.243$ and $n = 12$ $\Delta E/\Delta t = 15.5$ with $s = 1.964$ and $n = 12$
$6.73 < W_{eff} < 18.1$ with $n = 12$ $d_{TTS} = 0.32$ $CA = N - N_r = 2$

October Grand Average (Oct. 1-5 excluding Sunday, Oct. 2)
$\Delta = 0.66$ with $s = 0.3953$ and $n = 4$ $N = 39.3$ with $s = 5.2373$ and $n = 4$
$N_r = 37.8$ with $s = 4.7871$ and $n = 4$ $WSW = 19$ with $s = 5.099$ and $n = 4$
$P = 15.5$ with $s = 3.109$ and $n = 4$ $A = 3.25$ with $s = 1.2583$ and $n = 4$
$T = 10.51$ with $s = 0.0278$ and $n = 4$ $\Delta E/\Delta t = 13.5$ with $s = 1.564$ and $n = 4$
$5.93 < W_{eff} < 17.3$ with $n = 4$ $d_{MWF} = 0.35$ $d_{TTS} = 0.32$ $CA = N - N_r = 1.5$

Notes:
The average monthly water usage in miner's inches is much closer to the HUP least upper bound on W_{eff} than it is to the best upper bound (see next section). This is because few WSW and A waterers have been active long enough to measurably affect pond Δ. This has been established through measurements carried out on days when Boxwood Ranch was not irrigating and Carmichael had exclusive use of the RDB and the water supply flow from the gate 178 weir.

October data is presented as the grand average because there were too few watering days to make data by rotations comparisons meaningful. The last day of irrigation inspections was Wednesday, Oct. 5th owing to an electrical pump trip shortly after 2:00 AM on Oct. 6th.

Definition of Symbols

Δ = pond drop in ft. N = total number of active zones
N_r = number of residential zones active WSW = wet sidewalk count
P = gutter puddle count A = active sprinkler systems count
T = number of hours into the HUP $\Delta E/\Delta t$ = average kW power consumption during the period
W_{eff} = miner's inches drawn from RDB d = statistical duty cycle factor
s = standard deviation n = size of the sample

Carmichael's Average Daily Water Usage in 2016 by Month

The following table presents the statistical estimates for the upper bound on Carmichael subdivision's average daily water usage by month for May through October 7th. Because the method was under development in April and May there is not enough data to compute a reliable estimate for April.

Average Daily Water Usage by Month in 2016

Month	Average Usage (miner's inches)	Standard Deviation (miner's inches)	n	recommended W_o (miner's inches)
May	8.96	2.618	19	10
June	10.8	2.427	15	11
July	11.5	2.939	24	12
August	12.4	2.963	27	12
September	10.9	2.011	25	11
October 1-5	10.5	1.049	4	11

Average Daily ΔE/Δt and p-factors by Month in 2016

Month	ΔE/Δt (kW)		p-factor		n
	mean	std. dev.	mean	std. dev.	
May	12.7	0.970	0.831	0.103	15
June	15.1	1.806	0.872	0.061	15
July	15.99	1.476	0.852	0.048	24
Aug.	15.6	1.178	0.834	0.049	27
Sept.	13.5	1.177	0.847	0.051	25
Oct. 1-5	12.1	0.909	0.897	0.042	4

Grand average p-factor = 0.851 with std. dev. 0.0497 and n = 110

A Brief Primer on Statistics

A minimal statistical characterization of any randomly varying quantity requires three statistics: the arithmetic mean value ("the average") of the quantity; the standard deviation of the quantity; and the number of observations (n) upon which the statistics are based.

The mean is the average value of all the observations. This quantity can be easily calculated in an EXCEL™ spreadsheet using that program's built in AVERAGE function. Knowing the mean value allows the water master to predict the normal behavior of the quantity. We order to supply the average usage.

The standard deviation is a measure of how much variability is to be expected in a quantity. Generally any quantity observed at any one specific time will not equal the mean value. Its departure from this mean value is called its "deviation from the mean." Knowing the standard deviation provides you with a measure of how much the largest and smallest values of the quantity are expected to be if the system is functioning normally and no changes have occurred in it. Under normal conditions an observed value of the quantity will lie within 2 standard deviations of the mean value. For example, if the mean value of Δ is 0.92 ft. with a standard deviation of 0.2 ft., the normal range of observed pond drops will lie between 0.52 ft. and 1.32 ft. If an observed value of Δ falls outside of this range this is an indication that something unusual has happened. The situation should be investigated to find out if something is wrong because there is only about 1 chance in 20 that the system is operating normally. The standard deviation is also easily calculated in an EXCEL™ spreadsheet using its built in STDEV.S function.

A statistic is an estimate. Generally speaking, the *reliability* of this estimate improves as the number of observations, n, that go into calculating it increases. For example, from June 2 to June 11 in 2016, the mean value of HUP pond drop Δ for the TTS rotation was estimated at 0.75 ft. This estimate was based on n = 5 observations. 12 days later, on June 23, there were n = 9 observations available and the estimated average Δ increased to 1.12 ft. Generally speaking, the more observations n that you make, the greater the confidence you can have in the mean value of an observable quantity because the mean is based upon more data. Similarly, a standard deviation is also an estimate (an estimate of variability) and the reliability of the estimate it makes also improves as more observations n go into its estimation.

To continue with the June pond Δ data I just gave as an example, the estimated standard deviation based on the first n = 5 observations was s = 0.1205 ft. After n = 9 observations had been collected this estimate changed to s = 0.733 ft. As it turned out, these changes in Δ and s were *caused* by a problem that occurred in Boxwood Ranch's irrigation system, and this problem caused the flow of water into the CC to decrease for 4 days before the problem was identified and its effects corrected. The existence of the problem was discovered by the Carmichael water master on June 14 when he observed an abnormally large pond drop during morning inspection (2.86 ft., a change of 17 standard deviations from the mean as it was estimated on 6/11). It was narrowed down to something in Boxwood Ranch's system and identified by the Boxwood Ranch farmer as an act of vandalism on 6/15.

This example illustrates how statistics are used to identify occurrences of changes in conditions that affect the operation of the irrigation system. Statistics aren't just numbers. They are indicators of normality or abnormality in the operation of the system.

Statisticians speak of a "level of confidence" one can have in one's estimates. The number of data samples n is a key factor in establishing this confidence. Thus, the mean value, the standard deviation, and the number of observations are all necessary quantities for using statistics to characterize and manage Carmichael's irrigation system.

Last Day of Irrigation Season by Year

Year	Last Irrigation Day	
2013	Sept. 5	
2014	Oct. 4	
2015	Oct. 6	
2016	Oct. 7	(Anderson Ranch reservoir carryover into 2017: 31.2 AF)

Important Phone Numbers

Boise Project Water Master:	342-5086	
After hours BP emergency number:	489-6670	(tell the operator we are in Division 2)
Boise Project Pump Crew Chief (Jeremy)	871-6894	
Ditch Rider (Sean Pardew)	870-7719	
Boxwood Ranch (Lou)	867-4059	

Five Year Average Monthly High and Low Temperatures and Precipitation

The following table provides monthly average high and low temperatures and monthly precipitation data for Boise from 2012 to 2016.

Month	Year	Avg. Temperature		Precipitation	
		High	Low	(inches)	
April	1940-2015	61.7	37.4	1.20	(historical average)
	2012	66	43	2.01	
	2013	62	38	0.95	
	2014	62	39	2.13	
	2015	64	38	0.60	
	2016	68.4	42	0.69	
May	1940-2015	71.1	44.7	1.29	(historical average)
	2012	72	46	0.86	
	2013	74	48	0.77	
	2014	75	47	0.60	
	2015	74	50	1.50	
	2016	72.5	47.3	0.86	
June	1940-2015	79.9	51.9	0.84	(historical average)
	2012	82	53	0.19	
	2013	84	55	0.41	
	2014	81	54	0.17	
	2015	91	61	0.17	
	2016	85.1	55.1	0.22	
July	1940-2015	90.9	58.9	0.25	(historical average)
	2012	97	66	0.07	
	2013	98	65	0.13	
	2014	96	66	0.08	
	2015	90	63	1.57	
	2016	91	60	0.27	
August	1940-2015	88.6	57.6	0.28	(historical average)
	2012	94	63	0.00	
	2013	94	63	0.45	
	2014	89	63	0.13	
	2015	92	63	0.18	
	2016	90.5	60	0.00	
September	1940-2015	78.1	49.3	0.55	(historical average)
	2012	84	54	0.05	
	2013	78	55	1.75	
	2014	80	55	0.89	
	2015	80	53	0.51	
	2016	76.6	50.8	0.21	
October	1940-2015	64.8	39.7	0.81	(historical average)
	2012	65	41	0.98	
	2013	62	38	0.76	
	2014	70	46	0.40	
	2015	71	49	0.92	
	2016	65.2	44.5	0.00	(Oct. 1-6)

Anderson Ranch Reservoir End-of-July Water Storage

End of July Water Storage at Anderson Ranch Reservoir in thousands of acre feet

Year	Storage (kAF)	Year	Storage (kAF)	Year	Storage (kAF)	Year	Storage (kAF)	Year	Storage (kAF)
1946	2.9	1960	407.0	1974	442.0	1988	187.2	2002	271.6
1947	79.6	1961	220.8	1975	450.0	1989	387.0	2003	381.0
1948	105.2	1962	447.2	1976	412.1	1990	264.1	2004	304.0
1949	46.8	1963	449.4	1977	198.0	1991	184.1	2005	320.4
1950	242.6	1964	431.3	1978	443.8	1992	63.3	2006	392.6
1951	449.2	1965	461.8	1979	375.9	1993	417.0	2007	278.9
1952	445.0	1966	370.5	1980	435.6	1994	177.5	2008	392.1
1953	441.1	1967	453.5	1981	429.6	1995	448.9	2009	384.9
1954	439.3	1968	340.8	1982	458.6	1996	434.5	2010	387.0
1955	410.8	1969	442.4	1983	463.0	1997	435.8	2011	420.6
1956	457.4	1970	453.0	1984	464.0	1998	433.8	2012	374.0
1957	428.0	1971	456.7	1985	367.0	1999	425.9	2013	208.7
1958	425.9	1972	458.2	1986	457.4	2000	373.4	2014	374.0
1959	406.3	1973	402.6	1987	239.1	2001	132.7	2015	320.8
								2016	338.4

Data obtained from the Natural Resources Conservation Service

http://www.wcc.nrcs.usda.gov/basin.html .

Water Levels Observed in the Moore Lateral

Moore lateral water level (inches above flashboard)

Month	Average (inches)	Std. Dev. (inches)	Highest (inches)	Lowest (inches)	no. of data points
August	13.69	0.6746	14.7	12.25	56
Sept. 1-23	13.98	0.3368	14.75	13.25	23
Sept. 24-30*	3.24	1.0467	5.125	1.417	15
Oct. 1-5*	5.86	1.1804	7.25	3.5	10

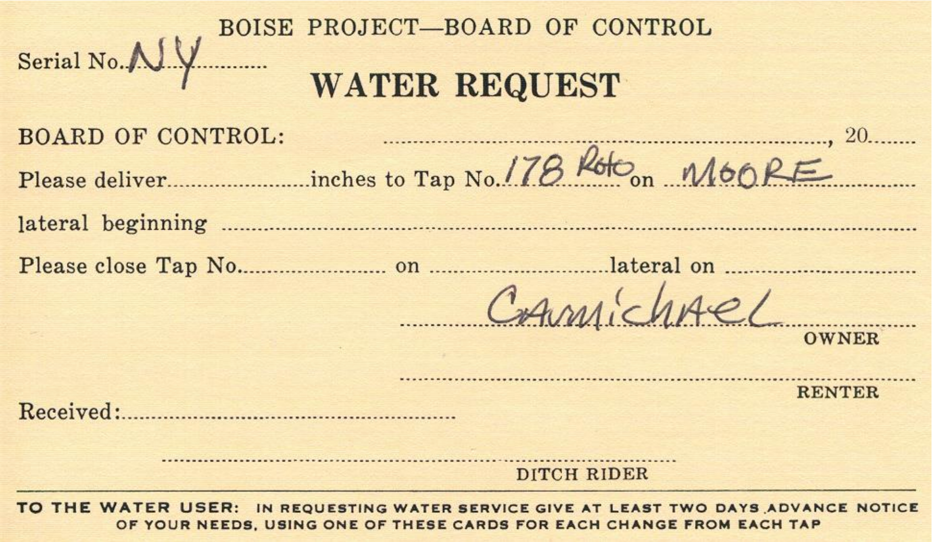
*Water supply controlled from headgate because Carmichael was last irrigator on the Moore lateral.

Inches of Spillover from the Main Cistern*

Month	Average (inches)	Std. Dev. (inches)	no. of data points	
July	1.527	0.6114	68	the weir supplied 15 MI until July 5, 20 MI after.
August	1.678	0.6300	66	the weir setting was unchanged all month (3.5")
Sept. 1-23	2.102	0.6434	40	water order reduced to 11 MI on Sept. 21 (3.25")
Sept. 24-30	0.854	0.6331	12	water supply controlled from headgate
Oct. 1-5	1.919	0.4769	10	water supply controlled from headgate

* measured when Boxwood Ranch was not irrigating. Statistics do not include times when the MC was below the spillway. Weir setting refers to the number of inches of screw protruding above the weir wheel and not to miner's inches. According to the ditch rider, 3.5 inches corresponded to a 20 MI total weir supply. Weir supply miner's inches are nominal setting values and do not include actual variations in supply.

Water Request Card



BOISE PROJECT—BOARD OF CONTROL

Serial No. NY

WATER REQUEST

BOARD OF CONTROL: ...., 20......

Please deliver.................inches to Tap No. 178 Roto on MOORE

lateral beginning ....

Please close Tap No................ on ....lateral on ....

Carmichael
OWNER

....
RENTER

Received:..

....
DITCH RIDER

TO THE WATER USER: IN REQUESTING WATER SERVICE GIVE AT LEAST TWO DAYS ADVANCE NOTICE OF YOUR NEEDS, USING ONE OF THESE CARDS FOR EACH CHANGE FROM EACH TAP

Important Formulas

Pond drop in kgal: $D_x \approx 2.47 + 19.3 \cdot \Delta$ where Δ = pond drop in ft. (see pp. 18-19)

HUP time interval covered by the morning inspection: $T = 11 - \Delta T$,
where ΔT = time between morning pond inspection and 8:00 AM.

HUP Water Usage: $W_{eff} = 1.667 \cdot N \cdot d - 1.852 \cdot \frac{19.3 \cdot \Delta + 2.47}{T}$ miner's inches (MI).

where $d \approx 1/3$ and
N = P gives the lower bound estimate W_{LB}
N = P + WSW + CA gives the middle range estimate W_{MB}

Average ΔE/Δt bound on a given day: $\overline{\Delta E/\Delta t} \leq 0.5 \cdot \left(\Delta E/\Delta t_{HUP} + \Delta E/\Delta t_{evening}\right)$

where $\Delta E/\Delta t_{HUP}$ = power reading taken during the HUP
$\Delta E/\Delta t_{evening}$ = power reading taken in the early evening

p-factor: $p = \overline{\Delta E/\Delta t} \div \Delta E/\Delta t_{HUP}$ (typical $p \approx 0.86$ when averaged over the month)

Water calibration estimate: $W_{CAL} = 0.5 \cdot (W_{LB} + W_{MD})$

Water usage estimate: $W \leq p \cdot W_{CAL}$ in miner's inches (MI).
W gives the daily estimate but W averaged over the month gives the average monthly usage.

Important URLs

Boise Project home page: http://boiseproject.net/
Carmichael water account summary page:
http://www.boiseproject.net/wateraccounting/login.aspx?ReturnUrl=%2fwateraccounting%2fWaterSummary.aspx
Water calculator: http://www.boiseproject.net/?pg=formulas
Number of days calculators:
http://www.timeanddate.com/date/durationresult.html?m1=7&d1=14&y1=2016&m2=8&d2=25&y2=2016
http://www.timeanddate.com/date/dateadded.html?m1=7&d1=14&y1=2016&type=add&ay=&am=&aw=&ad=45&rec=

About the Author

Richard B. Wells is a retired registered Professional Engineer licensed to practice in the state of Idaho. He holds a PhD. degree in electrical engineering and is an Emeritus Professor of engineering at the University of Idaho. Dr. Wells is internationally recognized as an expert in modeling and analysis of complex systems. He was a full time professor at the University of Idaho for twenty years doing teaching, research, and student advising. Prior to retirement his regular academic appointment was Professor of Electrical & Computer Engineering. He also held Adjunct Professor appointments to the Graduate Program in Neuroscience, the Department of Materials Science & Engineering, and the Department of Philosophy. From 2004 to 2015 he was an Affiliate Faculty member of the Department of Physiology and Biophysics at the University of Washington School of Medicine. Dr. Wells was a member of the Graduate Faculty at the University of Idaho. He annually advised from 13 to 62 undergraduate students. He was Advisor & Major Professor for 48 graduate students and served as Graduate Committee Member for another 73 graduate students in various academic disciplines. In addition he served as an Upward Bound Math and Science teacher for high school students. From 2004-2009 he was Principal Investigator and Program Director of the University of Idaho's annual Summer Neuroscience Research Experience for Undergraduates Program, funded by the National Science Foundation, which provided summer jobs and research training in neuroscience to gifted undergraduate students from 40 small colleges in 20 states. Student participants in this program annually won top honors at the National Student Research Competition including three Blue Ribbons for Best Student Research in the Nation.

Dr. Wells performed service work as member or chairman of numerous University committees and councils at the university, college, and department levels. He was founder and Director of the Wells Laboratory and served as Principal Investigator responsible for several million dollars in externally funded research contracts. From 1996 to 2011 he was Associate Director of the University of Idaho's MRCI research institute, at the time the largest research institute in the university. He is past Director of the University of Idaho's Neuroscience Program and past Associate Chair of the Department of Electrical and Computer Engineering. He served as a member of the University Wide Program Directors' Council and on the University of Idaho Research Council. Dr. Wells was a member of the University of Idaho Selection Committee for Department of Defense Experimental Research Contracts. In 2008 his work on understanding mathematics was adopted by and incorporated into the training program for mathematics teachers taught by International Baccalaureate®, an international non-government/non-profit organization in partnership with the United Nations Educational, Scientific, and Cultural Organization (UNESCO). In 2009-10 he served on a National Science Foundation panel in Washington, DC, evaluating and recommending programs to be funded by the 2009 American Recovery and Reinvestment Act.

Prior to joining the University of Idaho faculty he was employed for eighteen years with the Hewlett Packard Company where he worked as a Research & Development engineer and as a manager holding various management positions in Research & Development and in Manufacturing. Dr. Wells has published over 160 books, papers, and articles and holds four U.S. patents. He has been awarded numerous honors in recognition of his work. In September 2014 he began a three year term serving on the Carmichael Homeowners' Association's Board of Directors. In 2016 he served as Carmichael's resident water master.