Groundwater and Surface Water Interactions in Fifteenmile Creek Watershed, Oregon—*Results and Analysis from the 2008 Seepage Run*

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Open File Report SW 11 – 001

Salem, Oregon

July 2011

Abstract

In the summer and fall of 2008, OWRD completed multiple seepage runs in the Fifteenmile Creek watershed near The Dalles, Oregon. These seepage runs were completed in order to identify and quantify groundwater–surface water (GW/SW) interactions as part of a broader effort to analyze and enhance management of surface water and groundwater resources in the watershed.

The synoptic measurement data collected in 2008 and earlier seepage runs indicate various reaches of Fifteenmile Creek gain or lose water, sometimes alternating between gaining and losing reaches depending on the season and year. Observed stream flow losses have been as large as 93% – gains have been as large as 25%. Infrared temperature and specific conductance data generally corroborate seepage run results. . Preliminary hydrogeologic data suggests a connection between the Columbia River Basalt Group (CRBG) aquifer(s) and the stream network.

Seepage run data collected on Eightmile Creek, the main tributary to Fifteenmile Creek demonstrate similar results. Gains in the two creeks appear to coincide with exposures of the Frenchman Springs and Roza members of the CRBG. Gains are also associated with sedimentary deposits upstream of Endersby in Eightmile Creek and upstream of Dufur Oregon in Fifteenmile creek. Losses in the two creeks are coincident with outcrops of the Priest Rapids and Frenchman Springs members of the CRBG, or contacts between the two units. Geologic structures influence GW movement and seem to affect GW/SW interactions in the creeks.

The cause(s) of the apparent seasonal and yearly variation in GW/SW interactions is not known, but maybe related to recent groundwater development in the area.

Introduction

The Fifteenmile Creek drainage, including its principal tributary Eightmile Creek, is home to the easternmost run of wild winter steelhead in the Columbia Basin. Efforts have been underway to improve habitat and stream flow conditions in these two creeks to facilitate recovery of these federally listed “threatened” salmonids. Specifically, the Fresh Water Trust (FWT, formerly Oregon Water Trust) has been pursuing mechanisms to increase stream flow during the irrigation season in this fully appropriated watershed. These methods consist of transferring/leasing irrigation rights to an instream water right (ISWR) of sufficient water right priority (i.e., seniority) so that flow can be maintained and protected instream.

In addition to new–senior–ISWRs, there have been changes in agricultural practices in the watershed. Numerous acres of dry–land wheat have been converted to orchards. This conversion requires irrigation and, since surface water is fully appropriated, the additional water has come from further development of groundwater. The increase in groundwater withdrawals primarily occurred from aquifer(s) formed in the Columbia River Basalt Group (CRBG). Aquifers in the CRBG are susceptible to over drafting (Sceva, 1966; McCall, 1975; Grady, 1983; Norton and Bartholomew, 1984; Davies–Smith et. al., 1988; Lite and Grondin, 1988) due to low vertical permeability (which limits aquifer recharge), and high horizontal permeability (which allows for high withdrawal rates).

Understanding the watershed’s hydrology is critical for both management (e.g., managing instream flows and related regulation issues, and determining sustainable groundwater withdrawals) as well as scientific purposes (e.g., improving basic understanding of groundwater/surface water interactions in CRBG terrains).

In the summer and fall of 2008, OWRD completed multiple seepage runs to determine GW/SW interactions in both Fifteenmile and Eightmile Creeks near The Dalles, Oregon (Figure 1). These studies were funded, in part, by the National Fish and Wildlife Foundation (NFWF). Seepage studies are commonly used to identify GW/SW interactions between the stream and the adjacent flood plain or aquifer(s). The specific intent of this study was to identify if interactions occur, where they occur, and to quantify any losses or gains in stream flow that result from these interactions.

Prior to these NFWF-related seepage runs, the Watermaster was (and continues to be) very active gathering stream discharge data at multiple locations. This effort was initiated 2005 and includes multiple stream measurement data sets. This undertaking was also oriented at understanding GW/SW interactions (e.g., channel losses) and appropriately distributing water to users based on the hydrologic and regulatory setting. Information from these data sets are also analyzed in this report.

Background

Eightmile and Fifteenmile Creeks originate on the eastern slope of Lookout Mountain, a large shield volcano and the highest point (6,525 feet MSL) of Surveyors ridge (figure 1). From their origin, the creeks generally parallel each other, flowing northeast down the forested eastern slope of Surveyors ridge through the rolling dry–land wheat farms that occupy the mid to lower elevations of the watershed. Numerous perennial tributaries, which also originate along Surveyors ridge, contribute water to the two creeks; the most significant being Fivemile Creek (tributary to Eightmile Creek) and Ramsey Creek (tributary to Fifteenmile Creek). Several ephemeral tributaries drain to Fifteenmile Creek from the drier Tygh and Summit ridges; the southern and eastern boundary of the watershed, respectively. Approximately four to five miles south of the Columbia River and several miles east of The Dalles; Fivemile, Eightmile and Fifteenmile Creeks all turn northwards towards the Columbia River. Fifteenmile Creek eventually turns due west for several miles near Fulton Ridge before emptying into the Columbia River upstream of The Dalles. Eightmile Creek joins Fifteenmile Creek near Petersburg at approximately river mile (RM) three. Fivemile Creek flows into Eightmile Creek about 1.5 miles upstream of the Eightmile Creek mouth (figure 1).

The channel gradient of both Eightmile and Fifteenmile Creeks is high in the uplands and canyons, and generally lower, but locally significant in the valleys. Pool riffle combinations and channel substrates of bedrock and gravels/cobbles are common in the mid to lower reaches of both streams (Clark, 2003). In the study area, the creeks generally flow through either narrow basalt canyons or confined valleys with surficial alluvial deposits.

Like all watersheds, the hydrology of the Fifteenmile Creek watershed is primarily influenced by its climate and geologic setting. The watershed lies in the transitional zone between western Oregon’s humid maritime climate and eastern Oregon’s arid continental climate. The general climate characteristics of the watershed follows Oregon’s typical seasonal patterns of cool wet winters and warm dry summers, but is highly influenced by orographic effects of the Cascade Range to the west. The rain shadow cast by Mount Hood greatly reduces precipitation with distance from the Cascade Range. This precipitation pattern is also closely related to elevation, with the higher elevations of the watershed receiving greater amounts of precipitation (figure 2). The mean annual precipitation (MAP) near the headwaters of Fifteenmile and Eightmile Creeks is approximately 70 inches, while the MAP at Dufur (located near the centroid of the watershed) is only about 12 inches. The areal average precipitation over the watershed is about 19 inches per year (~370,000 acre feet, ac–ft). Temperatures vary dramatically with the seasons and spatially with elevation, with higher elevations being much cooler. Winter minimum temperature recorded at Dufur is commonly below freezing, while summer maximum temperatures often exceed 90°F.

Elevations in the 369 square mile Fifteenmile watershed range from 6525 feet in upper parts of the watershed to 83 feet at the mouth. However, the majority of the watershed (including the Eightmile Creek drainage) lies below the transient snow zone (~3000 feet), which means that precipitation in most of the watershed falls as rain. Nonetheless, snow fall and melt in the 12 percent of the watershed that lies above 3000 feet (near Surveyor’s Ridge and Lookout Mountain) is critically important for late spring and early summer stream flow. This mountainous area also receives the greatest amount of precipitation in the watershed (figure 2). Stream flow recorded at historic gages operated on both Fifteenmile and Eightmile Creeks demonstrate that peak flows occur throughout the winter in response to winter storms. However, stream flow also remains at a high rate during mid spring to early summer in response to snowmelt, gradually reaching low flow (base flow) conditions during summer (figure 3). Usually by mid July, stream flow is no longer sufficient to meet all water right demands, and regulation by the Watermaster begins. The mean annual flow for Fifteenmile and Eightmile Creeks is 79 cfs (57,000 ac–ft) and 36 cfs

(26,000 ac–ft). These values translate to runoff/precipitation ratios of 0.16 and 0.19, respectively. This indicates that for every inch of precipitation that falls in the Fifteenmile and Eightmile Creek watersheds, 16 and 19 percent is observed as stream flow, respectively.

The hydrogeology of the area is currently being investigated by OWRD and only a general description of the geologic setting, taken from various sources, (Newcomb, 1969; Baldwin, 1981; Bela, 1982; Grady, 1983; Walker and MacLeod, 1991; Orr et. al., 1992; written communications Marc Norton, OWRD) is given here. Most of the watershed is underlain by voluminous flood basalts (figure 4) of the Columbia River Basalt Group (CRBG) in excess of 3000 feet thick in places (Grady, 1983). This thick sequence of horizontal lavas flows have been tilted by tectonic forces northward from Tygh Ridge to the Columbia River and deformed and faulted. There are structural complexities at a range of scales in the watershed. The largest structural feature is The Dalles–Umatilla syncline (structural trough formed by deformation in the underlying geologic formations, [CRBG]) and associated Tygh Ridge anticline (ridge also formed by deformation in the underlying geology). The Columbia River occupies the apex of this syncline near The Dalles, while Tygh Ridge marks the apex of the anticline. This ridge/trough combination provides the framework for deposition of materials (i.e., Dalles Formation and high Cascadian volcanic rock) from the Cascades to the west. The tilting of the once-horizontal lava flows resulting from these large structures is thought to affect the general regional groundwater flow direction (Newcomb, 1969; Grady 1983).

Unconformably overlying the CRBG throughout the watershed is volcaniclastic mud and debri flows of the Dalles Formation. The formation is several hundred feet thick in many places, especially along ridges between the major streams. However, the stream network has eroded through this formation down to the underlying CRBG (figure 4) from the Japanese Hollow area to the mouth in Eightmile Creek, and from the city of Dufur's water intake to the mouth in Fifteenmile Creek (Bela, 1982). In these areas, the creeks flow over bedrock or surficial sedimentary deposits which overlay the bedrock. In addition, The Dalles formation is generally absent from Fifteenmile Creek southeast to Tygh and

Summit ridges (figure 4). Sedimentary deposits occupy the valleys of Fifteenmile and Eightmile Creeks. These deposits consists of alluvial, glaciofluvial and glaciolacustrine deposits (Grady, 1983); but are generally not shown in figure 4.

In the upper elevations of the watershed (the western quarter) are more recent volcanic and volcaniclastic rocks (e.g., basalt, basalitic andesite, andesite, etc) associated with Surveyor's ridge and Lookout Mountain—part of the present day Cascade Range east of Mount Hood. Surveyors' Ridge is formed by a North–South fault associated with the down–dropped Cascade graben containing Mount Hood, the Hood River drainage and associated valleys (Allen. 1965).

This geologic and climatic setting influences the hydrologic properties of Fifteenmile and Eightmile Creeks in two ways: by controlling the spatial distribution (in three dimensions) of permeable rocks and by dictating the spatial distribution and form of precipitation. Most of the watershed is underlain by the basalts of the CRBG lavas. The general hydrologic properties of the CBRG are well understood from past hydrologic studies (Newcomb, 1965; Newcomb, 1969; Newcomb, 1982; Norton and Bartholomew, 1984; Lite and Grondin 1988, Miller et. al., 1993): high lateral and low vertical permeability, and low infiltration rates. This is because only the lava flow tops and bottoms are typically permeable in the CRBG. These permeable layers can be separated by thick sequences of dense low permeable basalt, tens to hundreds of feet thick. At land surface, normally (i.e., without dramatic folds or inclines) exposed CBRG lavas will limit infiltration and groundwater recharge, resulting in most precipitation becoming runoff or returning to the atmosphere through evapotranspiration. The exception to this generality is where interflows (contacts between lava flows) are exposed (or lie under a permeable formation) and are tilted at land surface (Newcomb, 1969). In most of the watershed, the Dalles Formation overlies the CRBG (except as noted). The Dalles formation generally has both limited vertical and lateral permeability (Newcomb, 1963; Lite and Grondin, 1988), but may be locally permeable. Again, this setting tends to limit recharge and favor runoff. Further upland, along the flanks of Surveyors Ridge and Lookout Mountain, are the younger volcanic rocks associated with the current Cascades. These rocks tend to have moderate to high permeability (Lite and Gannett, 2002).

The structural folds and faults affect the watershed's hydrology at local and regional scales by influencing both shallow and deep water flow paths. Faults can act as both conduits and barriers to groundwater flow. There is at least one fault near Boyd that acts as a barrier to groundwater flow (oral communications Marc Norton, OWRD). Newcomb (1969) also noted structural barriers to groundwater flow in this area. The smaller synclines and anticlines influence hillslope surface and subsurface water flow paths, while the larger structural features (e.g., The Dalles Syncline) act on a larger scale to influence regional groundwater flow direction and surface drainage patterns.

The result of this geologic and climatic setting is that, for most of the watershed, vertical permeability is small, causing most precipitation to run off or evaporate, limiting groundwater recharge. In most of the southeast part of the watershed (Tygh and Summit Ridge) the CRBG extends from considerable depth up to land surface (figure 4). This area also has limited precipitation, which again falls predominately as rainfall. This setting explains the ephemeral nature of tributaries originating from this area. This area is probably not a significant source of recharge to groundwater, although Newcomb (1969) noted small springs in Standard and Douglass Hollow presumably from local recharge. Likewise, precipitation over the large expanses of Dalles formation (that overlies the CRBG in most of the watershed) probably mostly results in runoff, with only a small fraction recharging groundwater. Significant groundwater recharge is likely limited to areas near the headwaters such as Lookout Mountain. Here precipitation is much greater (and includes snowfall), the rocks younger and more permeable, and possibly additional deformation (and tilting) of the underlying CRBG occurs providing more opportunities for recharge. All of the perennial streams originate in this area, which indicates a higher degree of permeability (and infiltration) and ground water discharge to the stream network than elsewhere in the watershed. However, springs have been mapped in the middle and lower reaches of both creeks (Newcomb, 1969), indicating some groundwater does flow and discharge to the lower stream network.

The CBRG is an important groundwater resource in the watershed with wells tapping CBRG aquifers yielding very large quantities of water; some of which are artesian and flow at land surface. These aquifers are confined (at least locally) due to the low vertical permeability of overlying strata. Several various water bearing zones (i.e., aquifers) exist in the basalt members of the CRBG. These members consist of the Priest Rapids, Roza, and Frenchman Springs members of the Wanapum Formation; and the Sentinel Bluffs Unit of the Grande Ronde Formation (written communications Marc Norton, OWRD).

The contrasting characteristics of low recharge and high horizontal permeability can lead to dramatic water level declines in CBRG aquifers (Sceva, 1966; McCall, 1975; Bartholomew, 1975; Grady, 1983; Norton and Bartholomew, 1984; Lite and Grondin 1988). Indeed, The Dalles aquifer (also known as “The Dalles Ground Water Reservoir”) was declared a “critical groundwater area” by the state engineer in 1959 due to continued groundwater declines. Given the lack of significant base flows in the stream flow record, recharge and the regional groundwater system in the Fifteenmile Creek watershed are probably limited in terms of water volume. Mean daily flow hydrographs (figure 3) demonstrate that both creeks respond rapidly to rainfall and snowmelt events—a further indication of limited infiltration and groundwater recharge. Newcomb (1969) also theorized about the lack of groundwater recharge noting the small quantity of flow from springs in the area given the context of the CRBG aquifer characteristics.

Approach

In addition to discharge measurements from the seepage run, four other data sources were used to help characterize GW/SW interactions: temperature, specific conductivity, hydrogeologic data (general water levels and geologic data) and previous synoptic measurements made by the Watermaster. The methods associated with each data set are discussed below beginning with the seepage run.

Seepage runs (or synoptic measurements) are based on a mass balance for a stream determined by performing stream flow measurements on all surface inflows (e.g., tributaries) and outflows (e.g., diversions) along a reach of stream and on the stream itself in a short period of time—usually a day or two when the stream's flow is unchanging (i.e., steady). By accounting for all surface inflows and outflows in a stream reach, simple arithmetic can determine if the reach loses or gains water to the adjacent aquifer(s)/flood plain. If all surface water is accounted for, then any gain or loss of water probably results from interaction between the stream and the underlying aquifer(s).

Seepage runs are typically performed during low flow periods to reduce the effect of measurement uncertainty (typically five percent of the measured flow) on the results. Early fall is the best season to perform the measurements because irrigation activity is at a minimum, as is precipitation. Irrigation can complicate the analysis by adding multiple required flow measurements, each with its own level of uncertainty. Precipitation complicates the analysis by elevating stream flow and tributary inflow, and potentially creating local runoff; which is difficult to measure. Precipitation can also produce unsteady (i.e., rising or falling) stream flow conditions. Finally, precipitation can elevate groundwater levels compared to the dry season. Therefore, the most conservative time to perform a seepage run to protect existing water rights and identify channel losses is in the fall. However, because of previous observations of high summer channel losses, an additional seepage run was also performed during the summer.

Two seepage runs on Fifteenmile Creek were performed in 2008. The first occurred August 20th and the second September 30th (after irrigation season had ended). Prior to the seepage runs, the Watermaster scouted all potential inflows and diversions from RM 44 (Orchard Ridge Ditch) to the mouth (figure 5), as well as main stem measurement locations. Two stream gages were being operated on Fifteenmile Creek by FWT during the seepage run, one at Dufur Park (RM 30.5) and the other near Kasers Ranch (RM 6). Stage (river height) reference points and the gage data were to be used to verify steady state conditions during the seepage run. On August 20, 2008 a seepage run was conducted by OWRD and FWT field and technical personnel. All major inflows to the main stem were measured, and diversions were estimated using empirical methods. On September 30th, a second seepage run was completed by OWRD. A follow up set of discharge measurements was performed on October 1st, to confirm the discharge data collected on the previous day.

The Eightmile Creek seepage run occurred on November 18th, 2008. As with the Fifteenmile Creek runs, the Watermaster scouted for all potential inflows and diversions prior to the measurements from Wolf Run Creek (RM 16) to the mouth, as well as main stem measurement locations (figure 6). There was no operational stream gage on Eightmile Creek, but two reference stages were established and checked at the Eightmile road crossing to monitor for steady state flow conditions. Follow up measurements occurred on the following day.

Additional synoptic measurements were made on Fifteenmile Creek by the Watermaster between 2005 and the present. These data sets are at a coarser spatial resolution than the 2008 seepage runs, but are still informative as to location and magnitude of GW/SW interactions.

In addition to stream flow measurements, specific conductance measurements of water were taken along both creeks and at a few additional reference locations (e.g., springs, seeps, tributaries, etc,). These specific conductance measurements reflect the water's ability to conduct an electrical current and are related to the dissolved ion concentrations in water. Dissolved ion concentration in creeks is generally remain relatively constant, reflecting the short travel time (usually days) from the water's source to the mouth of the stream. The specific conductance of streams can be affected, however, by inflows of water with contrasting specific conductance. Groundwater, for example, often has specific conductance values much larger than stream water. This is due to the relatively long time (usually months to decades) groundwater has to interact with (and absorb ions from) aquifer materials along a flow path. Hence, specific conductance in streams generally increases with groundwater inputs. Given the measurement uncertainty inherent with seepage runs, specific conductance data is useful for substantiating calculated gains to the river.

Hydrogeologic information from well logs and well water level measurements are useful in determining aquifer static water levels (SWL), hydraulic head gradients (i.e., groundwater flow direction), geologic water bearing units, and temporal trends in groundwater levels. If an aquifers SWL is coincident or above that of the stream, then groundwater flow is likely towards the stream network and channel losses are extremely unlikely. Similarly, if water levels are below the stream then channel losses are possible but not certain, as channel seepage will still depend on streambed hydraulic conductivity. These generalities are more complicated for CRBG aquifers; which have thick sequences of low permeability basalts between water bearing zones, and between the creek and the water bearing zones. Interflow zones (contact point between lava flows) in the CRBG are areas of high permeability that can act as recharge or discharge areas with respect interactions with the stream network (Newcomb, 1969). A general head map (Grady, 1983), preliminary information from the current OWRD hydrogeologic investigation, and the general geologic map (Bela, 1982) was useful for interpreting the seepage run data.

Forward Looking InFared (FLIR) water temperature data from ODEQ (written communications Bonnie Lamb, ODEQ, 2008) was used to examine the longitudinal temperature profile of the creeks. Stream temperature usually declines where groundwater inflows occur, and generally increases in areas with no groundwater inflow or channel losses. However, diversions, channel shading, and hyporheic flow can make interpretation of the data difficult in some cases.

Results

Fifteenmile Creek–

A thunderstorm occurred in the watershed the night before the August 20th seepage run. The FWT gage pool at Dufur Park had been tampered with, making information from that gage unusable for verifying steady state conditions (i.e., rainfall–runoff response due to the thunderstorm). The FWT gage operated at Kasers had malfunction, but manual observations of the reference stage at Kasers suggests that unsteady stream flow conditions were present during the seepage run. At the beginning of the seepage run

(8:30 am) the observed stage at Kasers was 0.51 feet (ft), corresponding to a flow of 3.9 cfs (from rating curve). By 3:00 pm, the observed stage had risen to 0.53 ft; the equivalent of 4.3 cfs. The observed stage remained at 0.53 ft when observed at 7:00 pm, but had dropped to 0.49 ft (3.4 cfs) by 8:30 am the next morning (August 21st). These observations suggest that a pulse of water (from runoff) was in the study reach during the synoptic measurements. Based on the Watermaster's experience, the typical stream flow travel time between Dufur and Kasers is approximately one day. Estimates based on Manning's velocity equation gives a similar estimate of 12 to 16 hours, depending on the theoretical channel roughness coefficient. Based on this information, a pulse of water equivalent to at least 0.9 cfs over steady state conditions was present in the creek during the seepage run. There is insufficient flow information (as to the timing and extent of the water pulse) to correct the results for these unsteady state flow conditions. Therefore, no attempt is made to interpret this data set (figure 7).

The second seepage run occurred on September 30th. A follow up set of measurements occurred on October 1st to provide additional discharge data at key locations. The FWT gages were still inoperable, but stage observations at three locations (Kasers, above Kelly Cutoff, and Dufur Park) over two days indicated steady state conditions during this seepage run.

Results from the measurements are depicted as main–stem natural flows (MSNF) in figure 8. "Main stem natural flows" are the discharge measurements on the creek corrected for upstream inflows and diversions to reflect only changes in stream flow associated with GW/SW interactions. For example, if the measurement for Fifteenmile Creek at Dufur Park was 8 cfs and there was 1 cfs of tributary input upstream, then the MNSF at this locale would be 7 cfs. In this manner the measurement at Dufur Park can be compared to the next upstream measurement to examine GW/SW interactions. In this example, if the Fifteenmile Creek above Dufur point of diversion (POD) measurement (the next upstream location) was 5 cfs, and there was no tributary inflow, then the apparent change due to GW/SW interactions would be a 2 cfs gain.

Significant surface (i.e., tributary) inflows to Fifteenmile Creek occurred only from Ramsey and Eightmile Creeks. One diversion was in operation during the measurements and the estimated withdrawal was small (~0.1 cfs). Since all surface inflows and diversions are accounted for in the MNSF, differences in flow between adjacent locations can be attributed to GW/SW interactions. Although this difference is often less than the measurement uncertainty, several trends are noticeable in the overall results (figure 8). Fifteenmile Creek appears to gain water (i.e., groundwater inflows) between RM 40 (Dufur POD) and RM 27 (Boyd). Losses occur from RM 27 to the RM 13 (below Kelly Cutoff). However, between RM 13 and the mouth, groundwater inflows again contribute flow to the creek. The spatial distribution of gains and losses along with stream elevation are shown in figure 9. The stream elevation relative to groundwater elevations is discussed later in this document.

The second set of measurements on the following day was made at three follow up locations deemed critical for the analysis: RM 30.5 (Dufur Park), RM 15.5 (above Kelly Cutoff), and RM 6.0 (Kasers). Two measurements were made at each location. The results (open squares shown in figure 8) are in general agreement with the previous day's measurements at these locations. An additional set of measurements at the RM 13 (below Kelly Cutoff) would have confirmed the precise location of the transition between losing and gaining reaches. However, this site was not measured and, therefore, the second set of measurements indicated RM 6.0 (Kasers) as the low flow point. This result generally agrees with the Watermaster's synoptic measurements (discussed later) and experience (personal communications Bob Wood, Watermaster). Noteworthy is that if the "below Kelly Cutoff" measurement (from the previous day's seepage run) was erroneously low, the Kaser locale would have been indicated as the low flow point. In order to further investigate and confirm these gains and losses, the specific conductance data were analyzed.

The specific conductance (SC) data generally agrees with trends in main stem gains and losses (figure 8). The creek's SC increases in gaining reaches and remains relatively constant in losing reaches. The two significant increases in stream SC occur between RM

35.5 (below Ramsey Creek) and RM 27 (Boyd), and between RM 13 (below Kelly Cutoff) and the mouth; the same locations that were shown to have groundwater inflows from the discharge measurements. The specific conductance data also shows the low flow point (during the 2008 seepage run) was near RM 13 (below Kelly Cutoff). Noteworthy, is that the Fifteenmile's SC increases linearly throughout most of the lower reach between RM 13 and the mouth. Not until the last two river miles does this trend in stream SC appear to change (i.e., downstream of the Eightmile Creek confluence), reflecting a potential different source (i.e., aquifer) of inflows. The SC increases between RM 35.5 and RM 27, coincident with the gaining reach. A specific conductivity–mass balance was used to back calculate the specific conductance of the GW inflow to these reaches (see equations one and two).

specific conductance mass balance:

$$Q_{\text{Lower Site}} \text{ x } SC_{\text{Lower Site}} = \sum (Q \text{ x } SC)_{\text{tributaries}} + Q_{GW} \text{ x } SC_{GW} + Q_{\text{Upper}} \text{ Site x } SC_{\text{Upper Site}}$$

[EQ 1]

&

conservation of mass:

$$Q_{GW} = Q_{\text{Lower Site}} - \sum (Q)_{\text{tributaries}} - Q_{\text{Upper Site}}$$

[EQ 2]

The specific conductance of GW inflow between Ramsey Creek and Dufur was about 480µS, while the SC of the larger GW inflows in the next downstream reach (i.e., between Dufur and Boyd) was only 230 µS (figure 8). This latter value is very similar to the sampled SC of Eightmile Creek (238 µS) at the mouth and is identical to the groundwater SC estimate for GW inflows into Fifteenmile Creek in the last two river miles. The SC is also very similar to the estimate SC of groundwater inflows into Eightmile Creek above Endersby (discussed later). The specific conductance of the GW entering most of the lower reach (RM 13 to RM 2.75) is approximately 680 µS (figure 8). For reference, the specific conductance of various springs and tributaries are also included in this figure and are shown (in black) at their approximate location (i.e., river mile). The discharge from most of these springs and tributaries was very small (only a few gpm), but the affect can still be seen as a slight increase in SC in the creek in the losing reach (between RM 27 and RM 13). Some of these springs and seeps have similar SC values to the derived GW estimates.

The FLIR stream temperature data for Fifteenmile Creek was used to further examine the results from the seepage run. This ODEQ data was in August 2002 and is shown, along with seepage run results, in figure 10. Decreasing stream temperature in the downstream direction may be a sign of groundwater inflows. No “spring” sites were designated in the contractor’s review of the original data sets. However, there are areas with dramatic temperature declines (> 1-2°C) that could be indicative of diffused groundwater seeps (figure 10), as opposed to discrete spring vents which are easily identified in these types of data sets. The FLIR data generally agrees with the trends in main stem flow; stream temperature decreases are associated with increasing trends in stream flow (GW inputs). Likewise, stream temperature increases are associated with losing reaches. However, on the reach scale (i.e., between adjacent measurement sites), areas of potential seeps indentified from the temperature data do not always agree with the discharge measurement data (figure 10). The temperature data indicates a decrease in stream temperature (i.e., GW inflows) between RM 15 and RM 13, yet discharge measurements and specific conductance data do not indicate GW inflows. Below Kelly cutoff (RM 13) there are several reaches indicated as having GW inputs from the temperature data that did not show an increase in flow from the stream discharge measurements. This could be due to the uncertainty associated with discharge measurements. However, the trend in stream flow below RM 13 agrees with the trend in both FLIR and SC data.

Stream temperature decreases just upstream of Boyd, where discharge measurements and SC data indicate a gaining reach. Between Boyd and RM 15 (“above Kelly Cutoff” location) there are no significant temperature decreases (i.e., no GW inflows), which again agrees with the conductivity and discharge data of a steady or losing reach.

The Watermaster performed several sets of synoptic measurements to determine channel losses and distribute stream flow appropriately. These measurements were generally performed at four main–stem locations: RM 40 (Dufur POD), RM 30.5 (Dufur Park), RM 15.5 (above Kelly Cutoff), and RM 6.0 (Kasers). This data is also useful in examining results from the latest (2008) seepage run.

On August 22nd of 2005, the Watermaster measured 3.2 cfs at Dufur Park and only 0.2 cfs at Kasers, with no irrigation occurring between the two locations. If these measurements were made at steady state conditions (i.e., flow in the creek was not responding to regulation activities), then this represents a significant loss of 3 cfs (94%) exceeding the 0.8 cfs loss (13%) loss between these same locations during the 2008 seepage run. This information suggests that losses may vary by year, perhaps in response to natural climate- driven variations in aquifer water levels. Precipitation measured at the closest snotel site to the watershed (Clear Lake) shows that water year (WY) 2005 was much drier than WY 2008. Another cause of the variation could be changes in groundwater-level due to differences in pumping between the two years. Unfortunately flow meters are not present on many wells and historical information is limited.

Additional measurements made and tabulated by the Watermaster between 2005 and 2008 are shown in Tables 1.0 and 2.0 (written communications Bob Wood, Watermaster). The results are broken down into three reaches: an upper reach between Dufur POD (RM 40) and Dufur Park (RM 30.5), a middle reach between Dufur Park and above Kelly Cutoff (RM 15.5), and a lower reach between above Kelly Cutoff (RM 15.5) and Kasers (RM 6.0). Again if the creek was at steady–state conditions during these measurements (i.e., not rising or falling due to regulation or distribution), this suggests both seasonal and annual variations in GW/SW interactions. In the upper reach (upstream of Dufur Park) the measurement data indicates the creek almost always exhibits gains. However, in the middle (Boyd to Kelly Cutoff) and lower (Kelly Cutoff to Kasers) reaches, the creek either gains or losses water to varying degrees.

Interpreting streamflow data requires understanding of the associated uncertainty. One source of uncertainty is in the estimates of diversions. Diversions are not measured (except for canals), but are calculated based on assumed pressure and nozzle size for sprinkler sets which results in an estimated output per sprinkler head (~ 6 gpm). Field measurements of four randomly sampled sprinklers at two different irrigation lines at separate ranches have shown that this estimated flow rate is generally valid. However, without measurement devices to monitor both the amount and timing of the diversions, withdrawals have the potential to markedly affect the gain/loss calculation in some instances. Non-steady conditions may also introduce uncertainty. The lack of 15 minute discharge data at a gage site makes it difficult to verify steady state conditions are present during the seepage runs considered here.

As an example, in August of 2009 a follow up seepage run was made on Fifteenmile Creek. Even though the stream stage was not changing during measurements at the lower sites (e.g., Kasers, Below Kelly Cutoff, etc), there appeared to be a significant decrease in flow measured at Boyd (RM 27) in response to upstream surface irrigation withdrawals starting during the seepage run. Thus, even though the stage at the lower sites was stable, it was stable over a short period of time and did not reflect conditions throughout the study area. In addition, it takes time for the stream to re–equilibrate to any changes in withdrawals. Without gage data (or multiple reference stage checks before during and after the measurements) it is difficult to establish steady state conditions, especially with respect to unforeseen changes in irrigation diversions. This would be especially true during summer low flows when regulation of different users is occurring and where the effects of changing diversions would take time to propagate down the stream channel.

To reduce the potential effects of irrigation activities on the results, the previous synoptic measurements (from table 1 and table 2) associated with minimal diversions (< 1.5 cfs) were analyzed. In addition, since measurement error (as a percentage of the gains or losses) is higher when stream flow is high, only synoptic measurements made when the flow at RM 40 (Dufur POD) was below 10 cfs were examined. This analysis indicates variability in the magnitude and direction of the GW/SW interactions (figure 11). October measurements in 2005 and 2006 indicate a gaining reach between RM 30.5 (Dufur Park) and RM 15.5 (above Kelly Cutoff). This result is in contrast to the October 2008, August 2005, and September 2005 data. Again, this implies a seasonal and annual variation to the GW/SW interactions. The August, September and October 2005 data set in particular demonstrates this seasonal variation. The August 2005 measurements indicate substantial losses occurring below RM 30.5. These losses decreased in September and the affected reach begins to gain in October. This could be an indication that GW pumping seasonally reduces the hydraulic head in the underlying aquifer below that of the creek. The creek then losses water into the underlying aquifer(s). In the Eightmile Creek drainage, an investigation by the Watermaster and an OWRD hydrogeologist demonstrated interference between a well constructed in the Sentinel Gap basalt of the Frenchmen Springs Member (CRBG) and a nearby spring (Neal Spring) to Eightmile Creek (Marc Norton, OWRD,written communication). This is an example of how GW and SW are interconnected in the watershed and how GW pumping can affect spring discharge. Studies in the Mosier watershed (Lite and Grondin, 1988) and the Lost River watershed (Grondin, 2004) demonstrate that aquifer levels can be reduced by pumping, to the extent that flow reversal occurs at springs (i.e., springs become recharge point as opposed to discharge point for aquifers).

When interpreting seepage run data, it is often helpful to examine the geology and hydraulic head (i.e., water levels) in aquifers that intersect or are adjacent to the stream. In the case of this study, obtaining this information was complicated by four factors: 1) the existence of multiple aquifers with significantly different heads; 2) insufficient information to identify the water bearing units of the CRBG; 3) wells potentially constructed in multiple aquifers that comingle water and, therefore, have a composite SWL, and 4) lack of detailed published geologic mapping in the area. All of these limitations may be overcome with time and effort. OWRD is currently involved in a hydrogeologic study addressing some of these issues. Some general information is available from this and other studies.

A preliminary geologic cross section of the area coupled with static water level data indicates the water levels in the *Sentinel Bluffs* unit (an older, deep basalt) of the CRBG are higher than Fifteenmile Creek upstream of Boyd (Marc Norton, OWRD,written communication). As previously mentioned, a fault traversing Fifteenmile Creek near Boyd apparently impedes GW flow. Water levels are much higher south of this fault (upstream) than north of the fault (downstream). Specific conductance data (figure 8), suggests that groundwater discharge into the creek occurs from at least two different aquifers upstream of Boyd. This is consistent with 1:250k geologic map of the area (figure 4 and figure 12); with the creek in contact with predominately alluvial surficial deposits upstream of Dufur, and the Frenchman Springs member (CRBG) between Boyd and Dufur. The Dalles formation occupies most of the surrounding landscape upstream of Dufur and is a probable source of groundwater inflows as well. Analyzing static water levels and head gradient from water bearing units in these three geologic formations is complicated for reasons previously discussed, but would help in understanding GW/SW interactions. Upstream of Boyd, long term water declines of 50 to 100 feet have been observed in the Dufur and Boyd area (Marc Norton, OWRD, personal communication). The hydraulic head of some flowing artesian wells west of Dufur have dropped below land surface. This decline has the potential to affect GW/SW interactions in the area.

North of the fault (downstream of Boyd) (fig. 4), the 2008 seepage run data indicates a declining trend in stream flow (fig. 12). A general hydraulic head map of The Dalles basin developed in 1981 (Grady, 1983) based on groundwater level measurements taken in September–November of 1979 provides insights into this trend. The mapped hydraulic head drops below that of the creek just upstream of Emerson (RM 19.3) based on data collected in 1979. However, it’s unclear what aquifer(s) were mapped in the Grady study. Downstream of Boyd, the creek flows over various members of the CRBG (figures 4 and 12). Note that relatively shallow sedimentary deposits covering the CRBG formations in the narrow valleys downstream of Kelly Cutoff (RM 13) are not shown in either figure. Where the creek crosses contacts between formations (and between different basalts and flow units) are opportunities for GW/SW interactions between the creek and the aquifer(s). The contacts between the Roza and Frenchman Springs member are associated with either losing or gaining reaches downstream of RM13 depending on the year and the season (figures 11 and 12). There are several structural features which also may affect GW/SW interactions in this lower reach. Specific conductance data indicates that there maybe two distinct sources of inflows in this lower reach (figure 12).

The middle reach, identified between RM 27 (Boyd) and RM 13 (below Kelly Cutoff), is where the creek flows over the Priest Rapids member (between RM 19 and RM 11.5) and the Frenchman Springs member (between RM 27 and RM 19). This reach was identified as a losing reach from the 2008 seepage. Between RM 19 and RM 27, the creek has eroded through the Priest Rapids member and flows on top of the Frenchman Springs member (figure 4). Losses in this middle reach do not appear to be limited to a contact between CRBG members.

An alternative theory for the apparent seasonal and annual variation in GW/SW interactions is daily and seasonal changes in evapotranspiration (ET) losses from riparian vegetation associated with weather changes. However, studies demonstrating significant ET losses (as a percentage of streamflow) are typically associated with streams that have expansive riparian areas and flood plains, which contrasts to the losing reaches associated with Fifteenmile Creek. Nonetheless, the Watermaster noted that in late July 2009, dramatic losses were seen between RM 13 (above Kelly Cutoff) and RM 6 (Kasers) of approximately two cfs that coincided with extremely high temperatures in excess of 100°F in the area. (Note: A rough estimate could be made by mapping the areal extent of the riparian corridor, sampling the vegetation species and multiplying the area by the corresponding ET rate for the species.) Evaluating the potential ET effects on measured losses associated with an increase in air temperature of 10 to 20°F was beyond the scope of this study.

Higher temperatures, however, would also increase groundwater withdrawals to meet crop ET needs, which would also affect losses via stream capture. Newcomb (1969) noted that a 300 foot domestic well near Petersburg had SWL coincident with that of the adjacent Fifteenmile Creek, which is a likely indicator of hydraulic connection between

GW/SW. Evaluating if the change in GW/SW interactions is due to groundwater withdrawals was also beyond the scope of this study, but efforts to further evaluate this potential are underway. Information on changes to daily GW withdrawals would be required for this type of analysis which would require wide spread use of flow meters and more intensive stream gaging.

Eightmile Creek–

The seepage run on Eightmile Creek was performed on November 18th 2008, with an additional follow up seepage run on a subset of locations on November 19th. There are no active stream gages or staff gages on Eightmile Creek, so two reference points were established at pools in the creek near the Eightmile Road crossing verify steady state stream flow conditions during the measurements. There was some precipitation in the area about a week before the seepage run, but any corresponding runoff was thought to have passed through the creek; as conditions had been dry since that event. However, on the day of the first seepage run the creeks stage appeared to rise between the morning and afternoon. Follow up measurements in the afternoon (November 18th) at RM 16 (below Wolf Run) and at RM 8 (highway 97) were lower than the morning measurements indicating a pulse of water may have passed through the study area during the measurements. On November 19th, measurements were repeated at five locations. The monitoring pools remained steady during these measurements. Results from this second seepage run are presented in figure 13. The data for the November 18th seepage run are also presented, although there is more uncertainty with this data set.

Gaining and losing reaches identified on both days are in agreement, although the magnitudes differ; which is not surprising given unsteady conditions on November 18th. Eightmile Creek gains water between RM 16 (below Wolf Run) and RM 12.3 (Endersby), loses water between RM 12.3 and RM 7.8 (Highway 97), then gains water between RM 7.8 and the mouth of the creek. Specific conductance (SC) data also agrees with these gaining and losing reaches. SC increases in gaining reaches and remains relatively flat during losing reaches (figure 13). The spatial distribution of the gains is shown in figure 9.

FLIR data was collected for Eightmile Creek on August 3rd 2002 by Watershed Sciences LLC for ODEQ. A decline in stream temperature can be a sign of groundwater inflows. No springs or areas of localized groundwater discharge were identified in the contractor's review of the data sets. However, as with the Fifteenmile Creek data set, there are areas with notable temperature declines (> 1-2°C) that could be signs of diffused groundwater seepage (figure 13. The FLIR data generally agrees with the overall gain or loss in flow (figure 13). The November 18th seepage run was made at a finer spatial resolution than the measurements on the 19th. However, comparing the November 18th results with the FLIR results for specific reaches is not appropriate because of the unsteady flow conditions. The spatial resolution of the November 19th seepage run is not conducive for comparison to the reach specific FLIR data, but the overall trends in flow is in general agreement with the FLIR data. The FLIR data show two significant stream temperature decreases between Endersby (RM 12.5) and the highway 97 crossing (RM 7.8), even though this reach was found to be a losing reach during the November 2008 seepage run. This result could be a sign of seasonal changes in GW/SW interactions, similar to those seen in Fifteenmile Creek. Another explanation would be a stream temperature decrease resulting from other mechanisms (i.e., riparian shading). Still yet another explanation is that there is a smaller gaining reach (or hyporheic exchange) within the losing reach that was missed due to the large spatial resolution of the discharge measurements. The fault near Japanese Hollow (at RM 10.5) acts to impede GW flow (Marc Norton, OWRD, personal communication) and could be where the creek changes from a gaining to losing reach. Note the specific conductance increases slightly between RM 12 and RM 10, which also points to a smaller gaining reach between the two RMs.

The general hydraulic head map from Grady (1983) shows static water levels (SWL) above that of the stream network between RM 16 (below Wolf Run) and RM 12.5 (Endersby) by approximately 150 feet to 10 feet, respectively. This setting is conducive to a gaining reach and agrees with the seepage run showing this reach gains water. The general hydraulic head was approximately coincident with the stream network between RM 12.5 and RM 7.8 (highway 97 crossing). Newcomb (1969) noted that the creek cross an anticline ("Lash Ranch Anticline") near Japanese Hollow and water levels south (upstream) of this anticline were elevated to near valley altitudes. A slight decrease in SWLs from either anthropogenic or natural causes could drop the hydraulic head below that of the creek, which could cause the creek to lose water in this reach. Groundwater declines of 40-60 feet have been observed in wells in the Eightmile Creek watershed (personal communications Marc Norton, OWRD hydrogeologist). Measurements indicate this is a losing reach. Between RM 7.8 and the mouth, the mapped hydraulic head goes from coincident with land surface to approximately 50 feet higher than the creek at the mouth. In other words, the creek elevation drops faster than the groundwater levels going towards the mouth of the creek. Again, this information agrees with the identified gaining reach from the seepage run. The key information in interpreting this data is what aquifer (i.e., water bearing unit) is the basis of the mapped hydraulic heads and where does Eightmile Creek intersect this aquifer. Data from a preliminary geologic cross section of the area (written communications, Marc Norton OWRD hydrogeologist) generally agrees with water level findings described above and the water levels observed by Newcomb. The fault mentioned in the Fifteenmile description also transects Eightmile Creek upstream of Japanese Hollow (RM 10.5). Again based on SWL, this fault apparently acts as a barrier to GW flow (personal communications Marc Norton). South of this fault, hydraulic heads are higher and above that of the creek. North of the fault, the hydraulic heads are lower and generally at or below that of the creek. Further downstream the creek has incised to lower members of the CRBG and again is below that of the groundwater SWL. This area is coincident with the gaining reach identified during the seepage run.

Given that the creek elevation between RM 12.5 (Endersby) and RM 7.8 (highway 97 crossing) appears to be generally coincident with groundwater, the identified losses in this reach may vary by season and year in response to natural variation in GW recharge or anthropogenic stresses. Additional measurements would be needed to characterize any seasonal variation in GW/SW interactions.

The geologic data described previously was used to help interpret the results from the Eightmile Creek seepage run. The gaining reach upstream of Endersby is associated with the creek flowing over sedimentary deposits and The Dalles formation. However, the derived specific conductance of the groundwater inflow (240 uS) to this reach is similar to SC inflow associated with the Frenchman Springs contact in upper Fifteenmile Creek. This may indicate that the source of the inflows is really the Frenchman Springs member and not the alluvial deposits or The Dalles Formation. Similar to Fifteenmile Creek, the losing reach in Eightmile Creek is associated with the creek flowing over the Priest Rapids member (or a contact between the Priest Rapids and Frenchman Springs member). The next downstream reach gains water occurs where the creek flows over the Frenchman Springs member and Roza member of the CRBG (figure 14). This result is similar to the results in lower Fifteenmile creek (figure 11). The derived specific conductance in this lower reach of Eightmile Creek is 460 uS, which is peculiarly dissimilar to the GW SC estimate in lower Fifteenmile Creek.

Conclusions

Seepage run data collected in the fall of 2008 indicate GW/SW interactions occur in Fifteenmile Creek. This data, as well as previous synoptic measurements, indicate some reaches consistently gain or lose water, while other reaches either gain or lose depending on the season and year. Observed stream flow losses have been as high as 93% gains have been as large as 25%. FLIR and specific conductance data generally corroborate the discharge measurement data. Preliminary hydrogeologic data also indicates some type of connection between the underlying CRBG aquifer(s) and stream network. However, the cause of the apparent variation in GW/SW interactions is not known. Potential causes included natural climate-driven variations in groundwater levels, pumping induced changes in groundwater levels, and riparian ET losses.

Likewise, seepage run data collected in the fall of 2008 on Eightmile Creek also indicate that GW/SW interactions occur and a connection between the creek and the underlying aquifer(s). Given that the geologic setting for Eightmile Creek is similar to that of Fifteenmile Creek, seasonal and annual variations in the losses are possible. Additional data sets would be required to evaluate any variability in GW/SW interactions.

Gains in the two creeks appear to coincide with the Frenchman Springs and Roza members of the CRBG. Gains are also associated with sedimentary deposits upstream of Endersby in Eightmile Creek and upstream of Dufur in Fifteenmile creek. Losses in the two creeks are coincident with the Priest Rapids and Frenchman Springs members (or contacts between the two) members of the CRBG. Geologic structures influence GW movement and seem to affect GW/SW interactions in the creeks.

Recommendations

The connections between groundwater and the stream network have been identified in this study. The degree of the connection needs to be further evaluated. More frequent and closely spaced stream discharge data sets would be very helpful in characterizing the nature of seasonal and annual changes in GW/SW interactions. Specifically, two stream gages located at Boyd (the high flow point) and Kaser (one of two potential low flow points) would be particularly useful. In addition, a staff gage at the “below Kelly Cutoff” location would also be beneficial to the analysis. Continuous groundwater-level data from a well near the stream network in the Kelly Cutoff and Kaser reach would provide insights into the relative elevations between the stream and head in the aquifer. In addition, a staff gage near the mouth of Eightmile Creek would aid in future seepage runs on that system. Flow meters on all surface water diversions and all significant groundwater withdrawals would aid in the analysis of the variation in GW/SW interactions and understanding the basins hydrogeology. Metering surface water diversions would greatly reduce the uncertainty associated with future seepage runs and analysis of gage records. Metering groundwater withdrawals or closely monitoring water levels in wells, would greatly aid in determining anthropogenic influences on channel losses. A water quality (i.e., chemical composition) synoptic set of measurements at wells and along both creeks would help understand flow paths, the aquifer(s) and where these aquifers interact with the stream network. Detailed mapping of the creeks intersection with various interflows of members of the CRBG would help understand GW/SW interactions. Finally, a detailed hydraulic head map for each would be helpful for understanding the spatial distribution of gains and losses.

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Table 1.0: Watermaster Stream Flow Measurements (2005-2006)

Fifteenmile Creek Streamflow Data- Cubic Feet per Second (cfs)

Date	Dufur POD (RM 40)	Ramsey Cr (RM 35.5)	Use Upper Reach	Dufur Park (RM 30.5)	Use Middle Reach	Kelly Cutoff (RM 15.5)	Use Lower Reach	Kaser's (RM 6.0)
RM (for plotting	**40**	**35.5**		**30.5**		**15.5**		**6**
7/11/2005	6.37	1.20	1.42	6.15	0.00	Unknown	0.40	3.37
				0.00			**Loss =**	**-2.38**
7/25/2005	4.80	0.20	2.35	2.03	0.00	Unknown	0.15	0.76
			Loss =	**-0.62**			**Loss =**	**-1.12**
8/22/2005	4.05	0.20	0.80	3.23	0.00	Unknown	0.00	0.23
			Loss =	**-0.22**			**Loss =**	**-3.00**
9/6/2005	4.26	0.50	2.20	2.56	0.00	1.41	0.00	0.35
				0.00	**Loss =**	**-1.15**	**Loss =**	**-1.06**
9/20/2005	3.84	0.50	1.50	2.84	0.00	2.28	0.00	3.16
				0.00	**Loss =**	**-0.56**	**Gain=**	**0.88**
10/14/2005	4.33	1.14	0.00	5.47	0.00	5.66	0.00	6.48
				0.00	**Gain=**	**0.19**	**Gain=**	**0.82**
2/23/2006	26.60		0.00	38.50	0.00	90.90	0.00	
			Gain=	**11.90**	**Gain=**	**52.40**		
3/31/2006	29.40		0.00	48.60	0.00	87.40	0.00	93.10
					Gain=	**38.80**	**Gain=**	**5.70**
4/18/2006	47.40		0.00	73.80	0.00	Unknown	0.00	143.00
							Gain=	**69.20**
5/17/2006	73.40	6.00	4.34	75.30	0.13	86.00	1.79	82.30
					Gain=	**11.00**	**Loss =**	**-1.91**
6/15/2006	39.80	3.00	2.89	42.80	0.08	55.10	3.33	50.70
					Gain=	**12.38**	**Loss =**	**-1.07**
July	No Mmt's							
8/10/2006	8.15	0.90	5.24	3.81	0.09	2.83	0.16	4.26
				0.00	**Loss =**	**-0.89**	**Gain=**	**1.59**
8/31/2006	7.23	0.50	1.83	4.92	0.00	3.39	0.36	2.65
				-0.98	**Loss =**	**-1.53**	**Loss =**	**-0.38**
10/17/2006	6.22	2.64	0.00	8.86	0.00	11.02	0.44	10.03
				0.00	**Gain=**	**2.16**	**Loss =**	**-0.55**

Ramsey Creek flows are estimates unless noted otherwise.

Irrigation use is estimated by counting sprinklers in use on a given day.

 # sprinklers x 6 gpm = approximate use in gallons per minute. gpm / 448.8 = Use in cubic feet per second.

Table 2.0: Watermaster Stream Flow Measurements (2007-2008)

Fifteenmile Creek Streamflow Data- Cubic Feet per Second (cfs)

Date	Dufur POD (RM 40)	Ramsey Cr (RM 35.5)	Use Upper Reach	Dufur Park (RM 30.5)	Use Middle Reach	Kelly Cutoff (RM 15.5)	Use Lower Reach	Kaser's (RM 6.0)
2/7/2007	20.80	5.00	0.00	28.10	0.00	Unknown	0.00	45.70
			Gain=	**7.30**			**Gain=**	**17.60**
3/26/2007	51.40	15.00	0.00	64.30	0.00	Unknown	0.00	88.60
			Gain=	**12.90**			**Gain=**	**24.30**
5/4/2007	27.90	5.87	6.67	27.10	2.08	34.20	3.50	30.90
			Gain=	**0.00**	**Gain=**	**5.02**	**Gain=**	**0.20**
6/6/2007	22.20	2.00	6.17	16.50	0.67	20.20	2.21	16.20
			Loss=	**-1.53**	**Gain=**	**4.37**	**Loss =**	**-1.79**
				-9.3%		**21.6%**		**-11.0%**
7/10/2007	5.80	0.50	3.44	2.69	0.54	1.48	0.21	0.95
			Loss=	**-0.17**	**Loss =**	**-0.67**	**Loss =**	**-0.32**
				-6.3%		**-45.3%**		**-33.7%**
8/9/2007	6.28	0.56	3.75	3.09	0.00	2.30	0.35	0.75
			Loss=	**0.00**	**Loss =**	**-0.79**	**Loss =**	**-1.20**
				0.0%		**-34.3%**		**-160.0%**
9/11/2007	5.13	0.50	2.01	3.32	0.04	3.16	0.00	2.26
			Loss=	**-0.30**	**Loss =**	**-0.12**	**Loss =**	**-0.90**
				-9.0%		**-3.8%**		**-39.8%**
4/25/2008	24.60	6.00	0.00	34.90	0.80	41.80	1.06	41.50
			Gain=	**4.30**	**Gain=**	**7.70**	**Gain=**	**0.76**
8/20/2008	8.57	1.65	6.55	5.08	0.87	4.36	0.00	4.79
			Gain=	**1.41**	**Gain=**	**0.08**	**Gain=**	**0.18**
10/1/2008	5.60	1.47	0.00	7.41	0.12	6.97	0.00	6.88
			Gain=	**0.34**	**Loss =**	**-0.38**	**Loss =**	**-0.34**

Ramsey Creek flows are estimates unless noted otherwise.

Irrigation use is estimated by counting sprinklers in use on a given day.

 # sprinklers x 6 gpm = approximate use in gallons per minute. Gpm / 448.8 = Use in cubic feet per second.

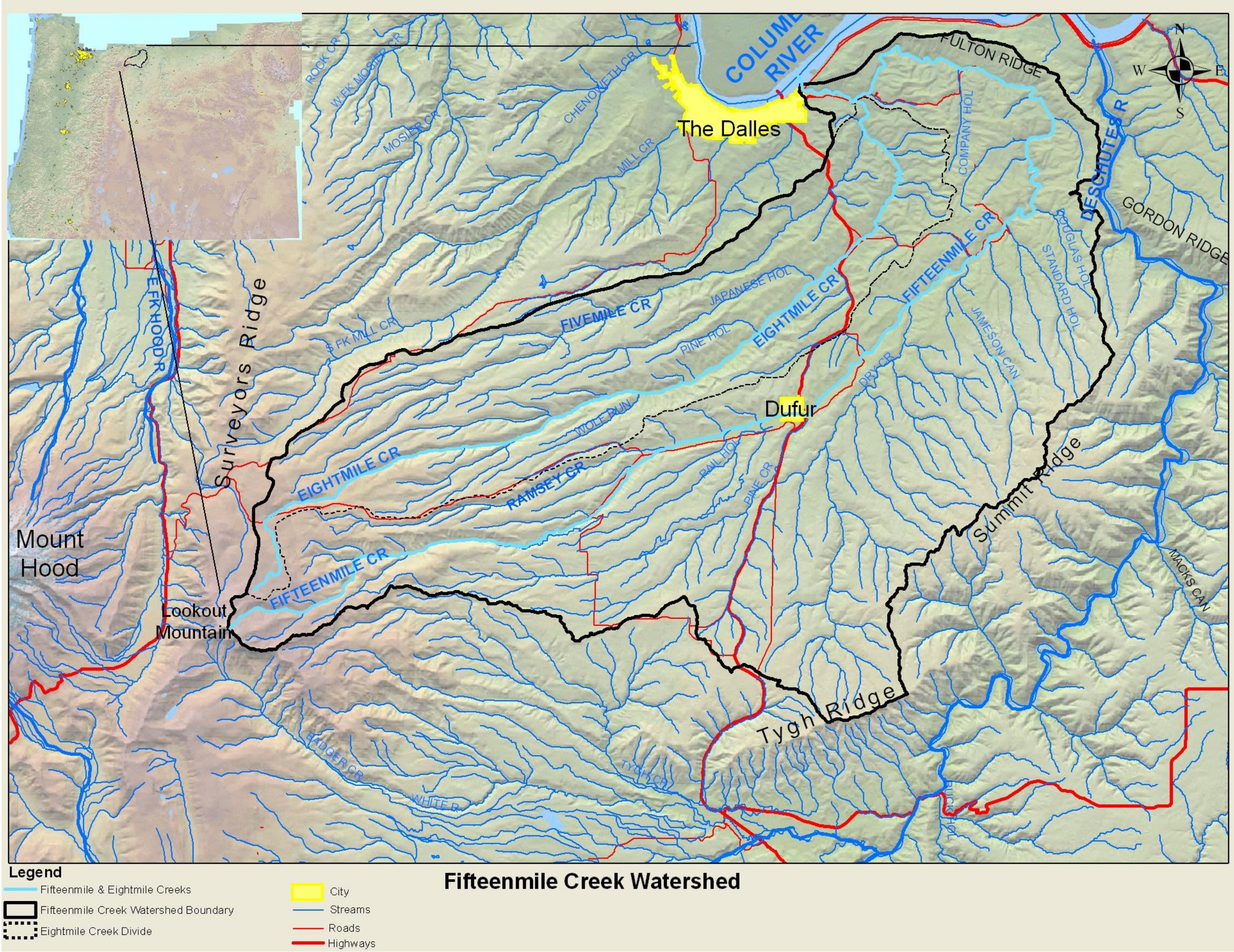
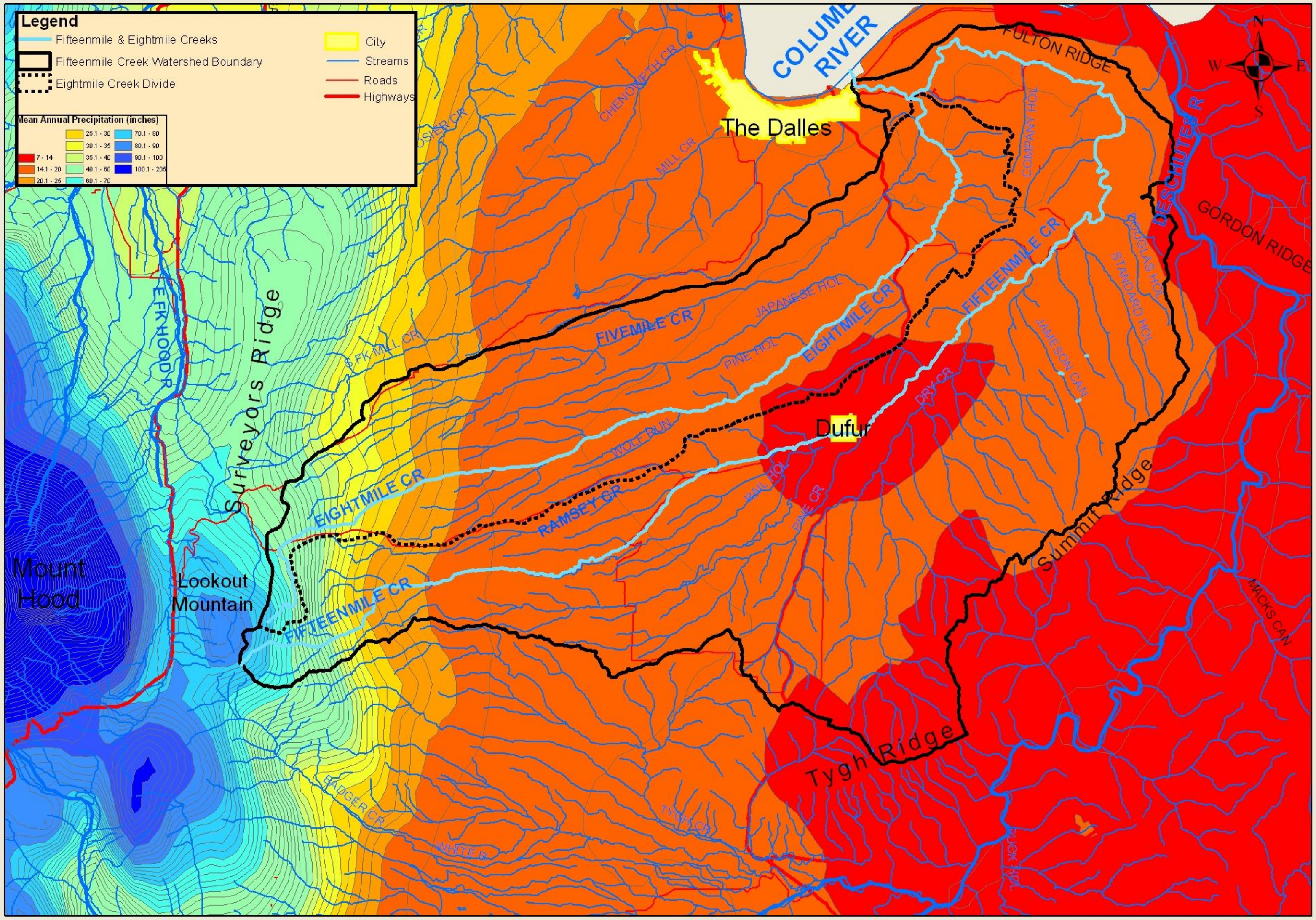


Figure 1: Fifteenmile Creek watershed location



Fifteenmile and Eightmile Creek Mean Annual Precipitation
(USDA/NRCS National Cartography & Geospatial Center, accessed September 2009)

Figure 2: Mean Annual Precipitation (1971-2000), from PRISM Project (Daly et.al., 1994; Daly et.al., 2002).

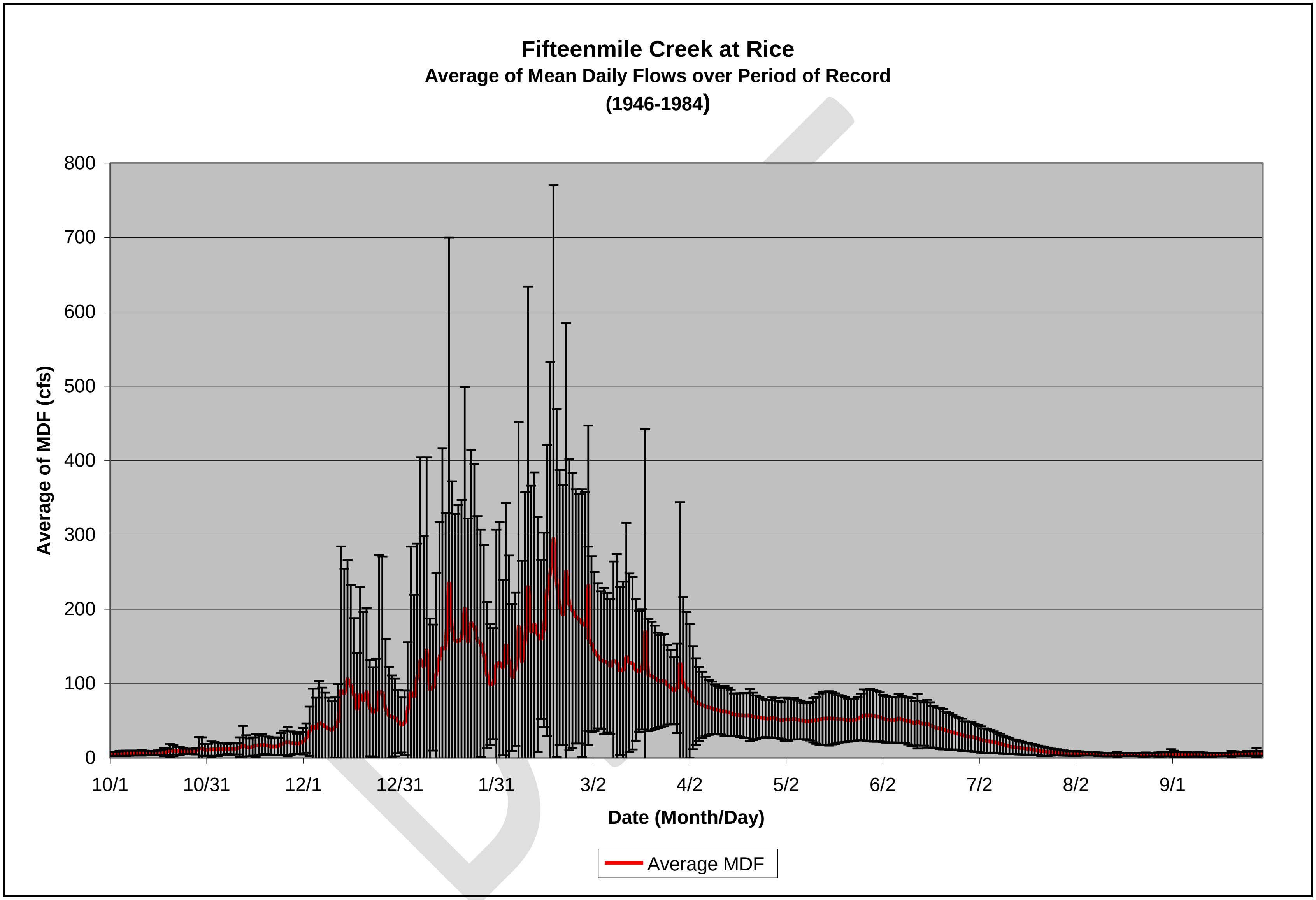
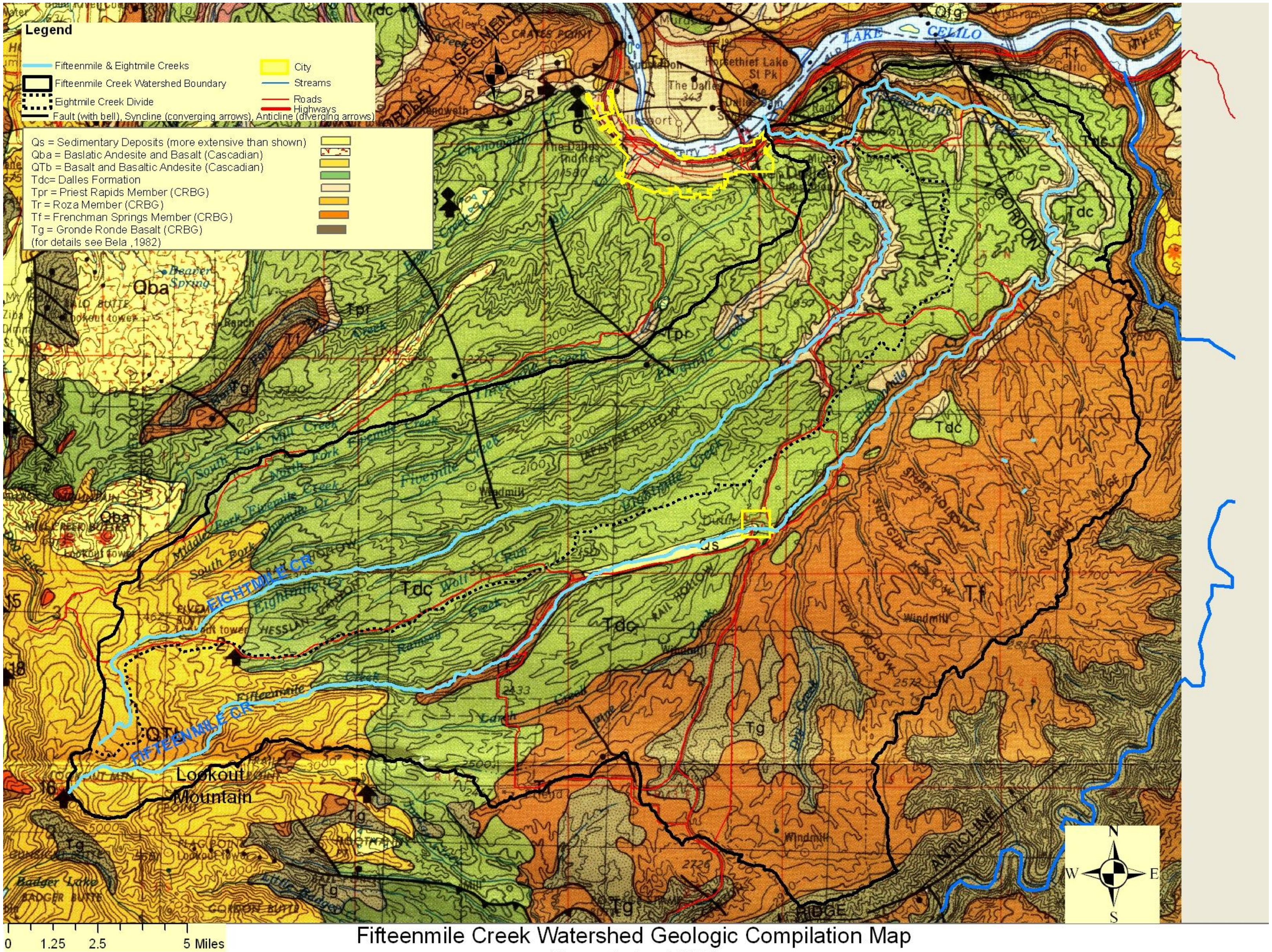


Figure 3: Average of Mean Daily flows recorded for Fifteenmile Creek at Rice Oregon (above Eightmile Creek Confluence). Envelope shows variation in flow over record (i.e., +/- 1 standard deviation of MDF for each day). Snow melt runoff is evident from April through June. Note lack of base flows in summer and fall.



Fifteenmile Creek Watershed Geologic Compilation Map
(from Bela, 1982)

Figure 4: Fifteenmile Geology 1:250k, Cropped from the “Geologic Compilation Map of The Dalles 1° by 2° Quadrangle, Oregon and Washington”

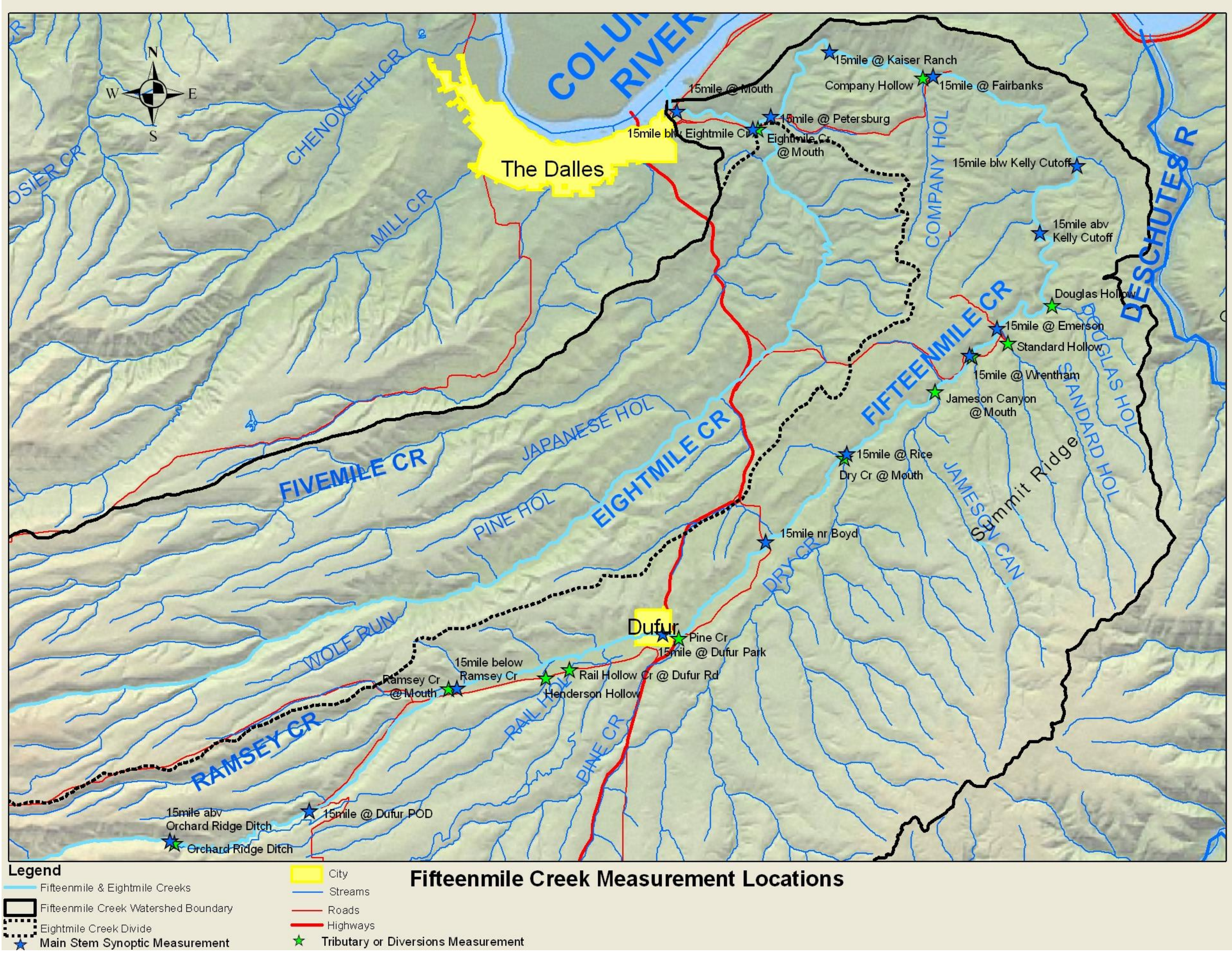


Figure 5: Fifteenmile Creek Measurement Locations. All diversions were checked during seepage runs. All spring locations where checked for inflows to the creek.

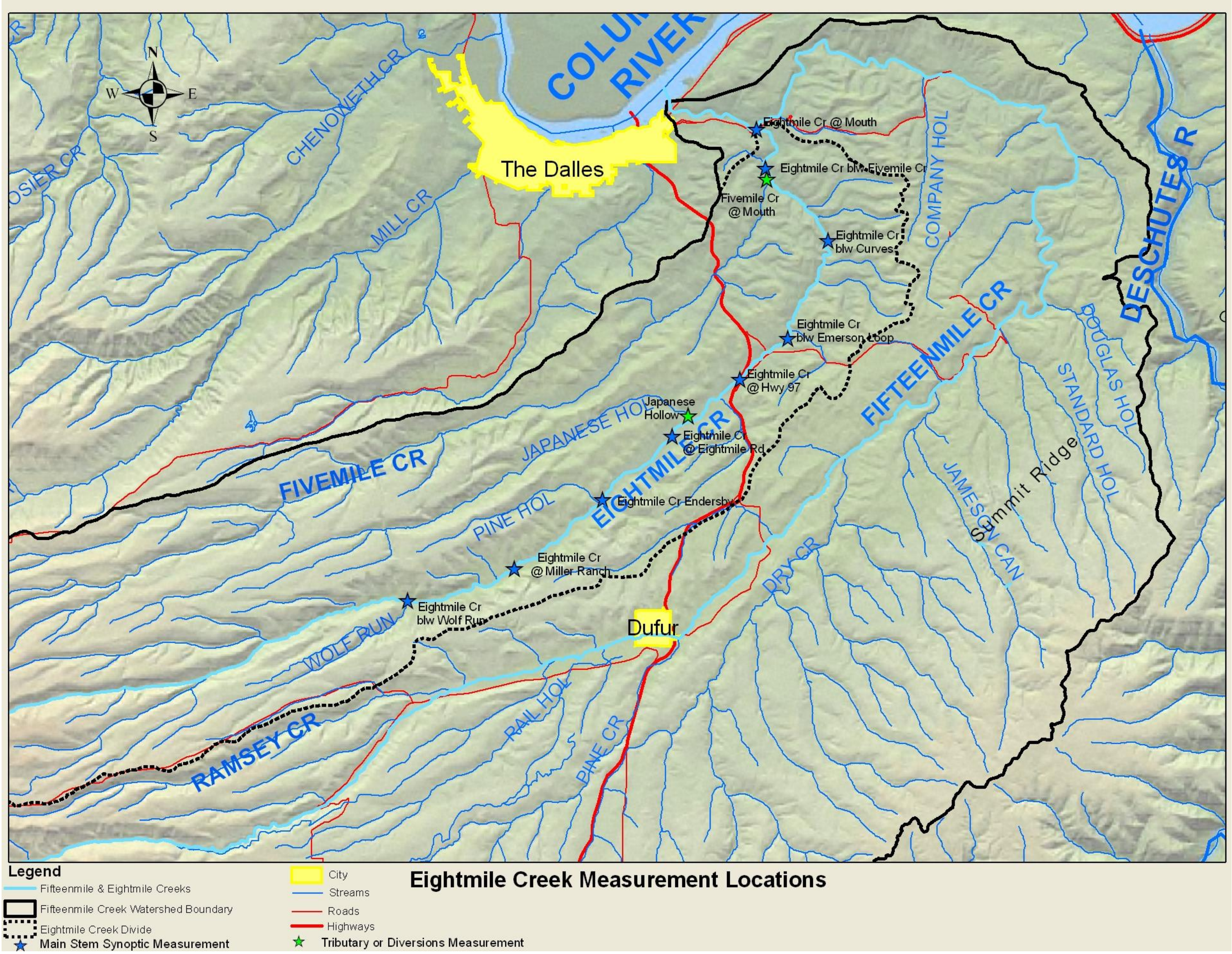


Figure 6: ~~Fifteenmile~~ Eightmile Creek Measurement Locations. All diversions were checked during seepage runs. All spring locations where checked for inflows to the creek.

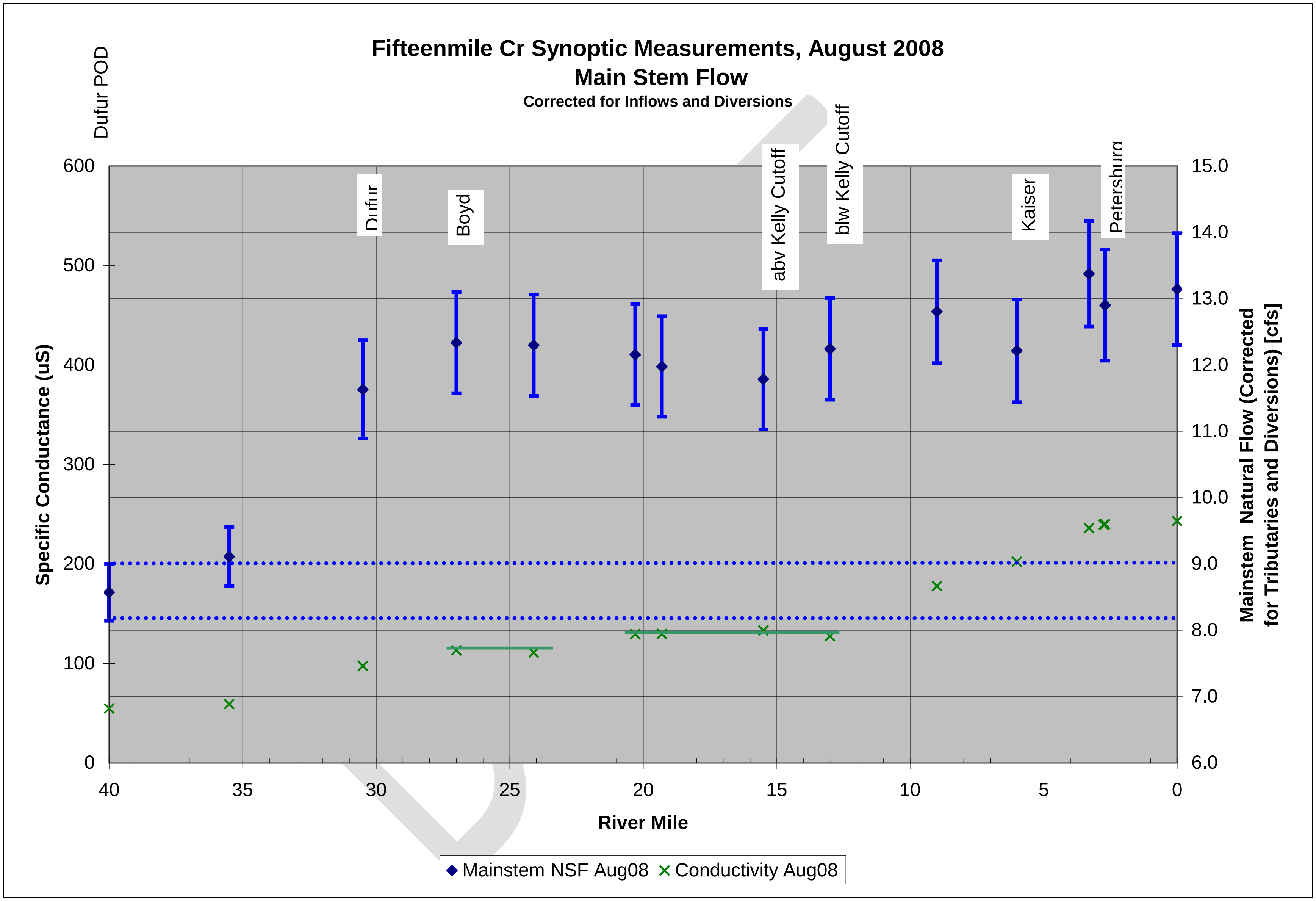


Figure 7: Fifteenmile Creek discharge corrected to main–stem natural flow. The blue line represents measured flow entering the study area (i.e., measured at Dufur), with dashed blue lines representing +/- uncertainty of the inflow to the reach. Error bars for each measurement location are shown. Measurements were made during unsteady flow conditions. Specific Conductivity measurements are show in green.

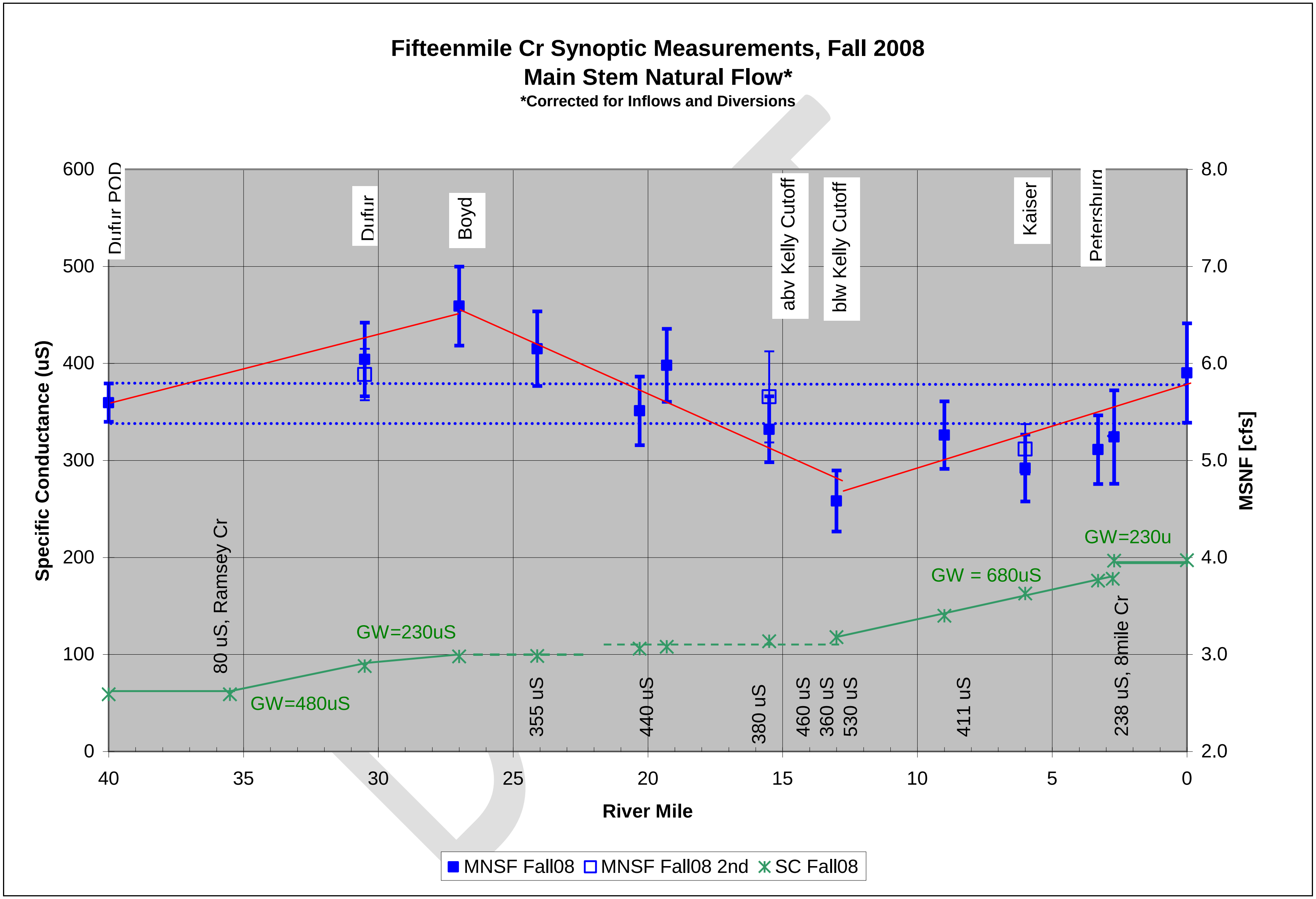


Figure 8: Fifteenmile Creek discharge corrected for upstream inflows and diversions (i.e., main–stem natural flow). The dashed blue lines represents inflow (+/- uncertainty) to the study area (i.e., Dufur POD). Check measurements are show in open blue squares. Error bars for each measurement location are shown (solid blue). Specific Conductivity measurements are show in green. Apparent trends are show in red.

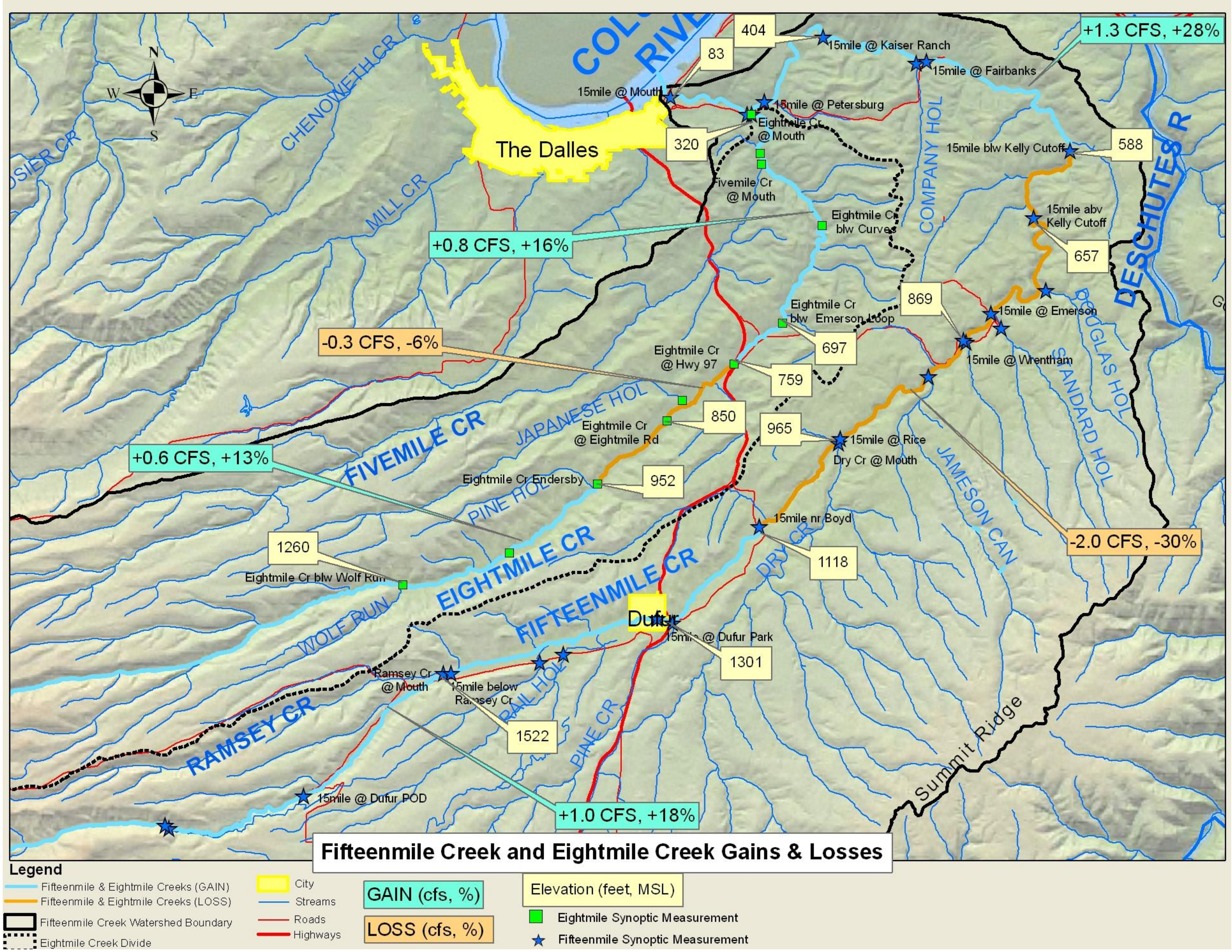


Figure 9: Fifteenmile and Eightmile creek gains and losses from 2008 seepage run.

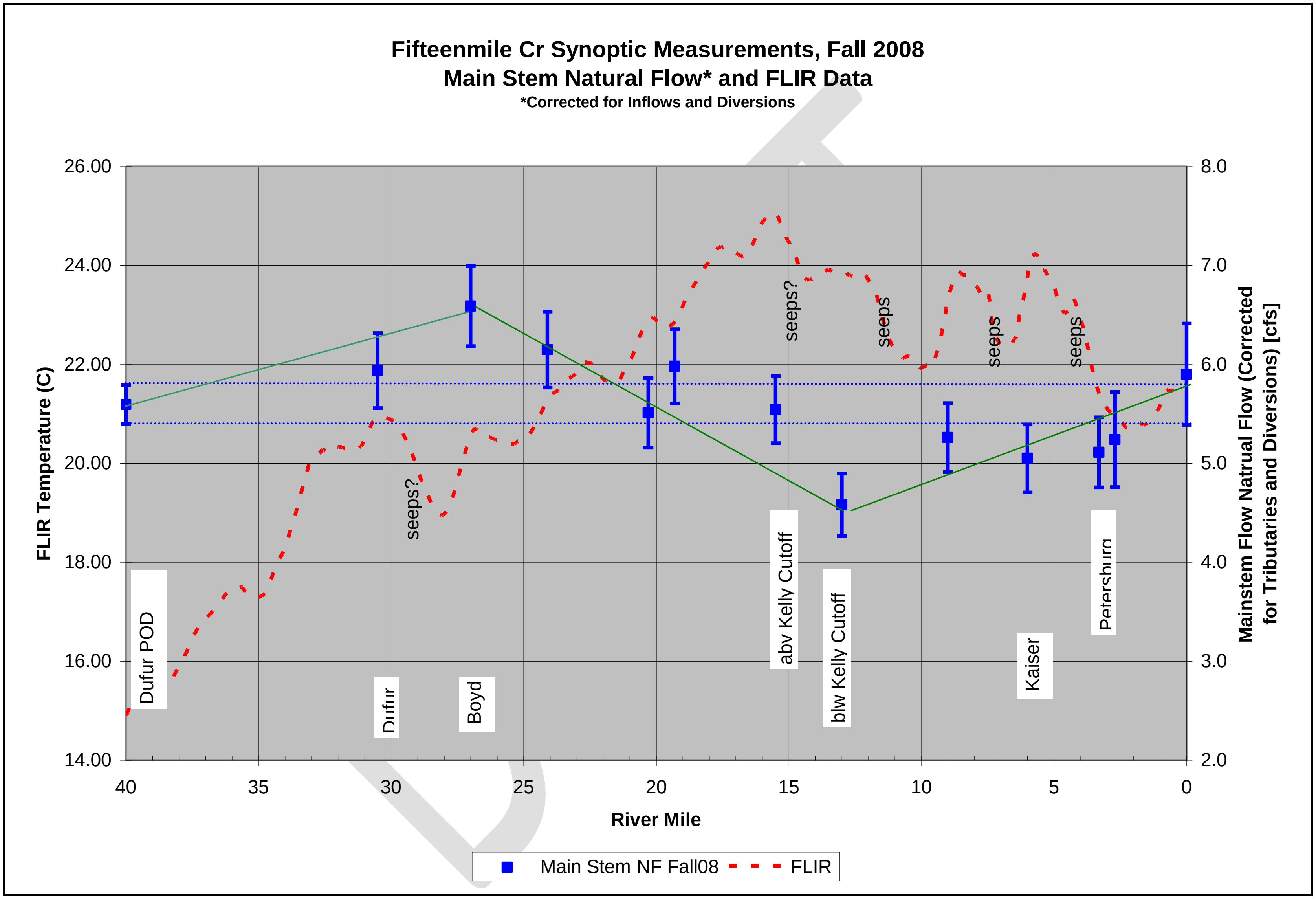


Figure 10: FLIR Stream Temperature Data and Reach Gain/Loss. “seeps?” indicated where dramatic stream temperature decreases occur, probably in response to groundwater inflows. Stream flow trends (i.e., main stem gains or losses are shown in green)

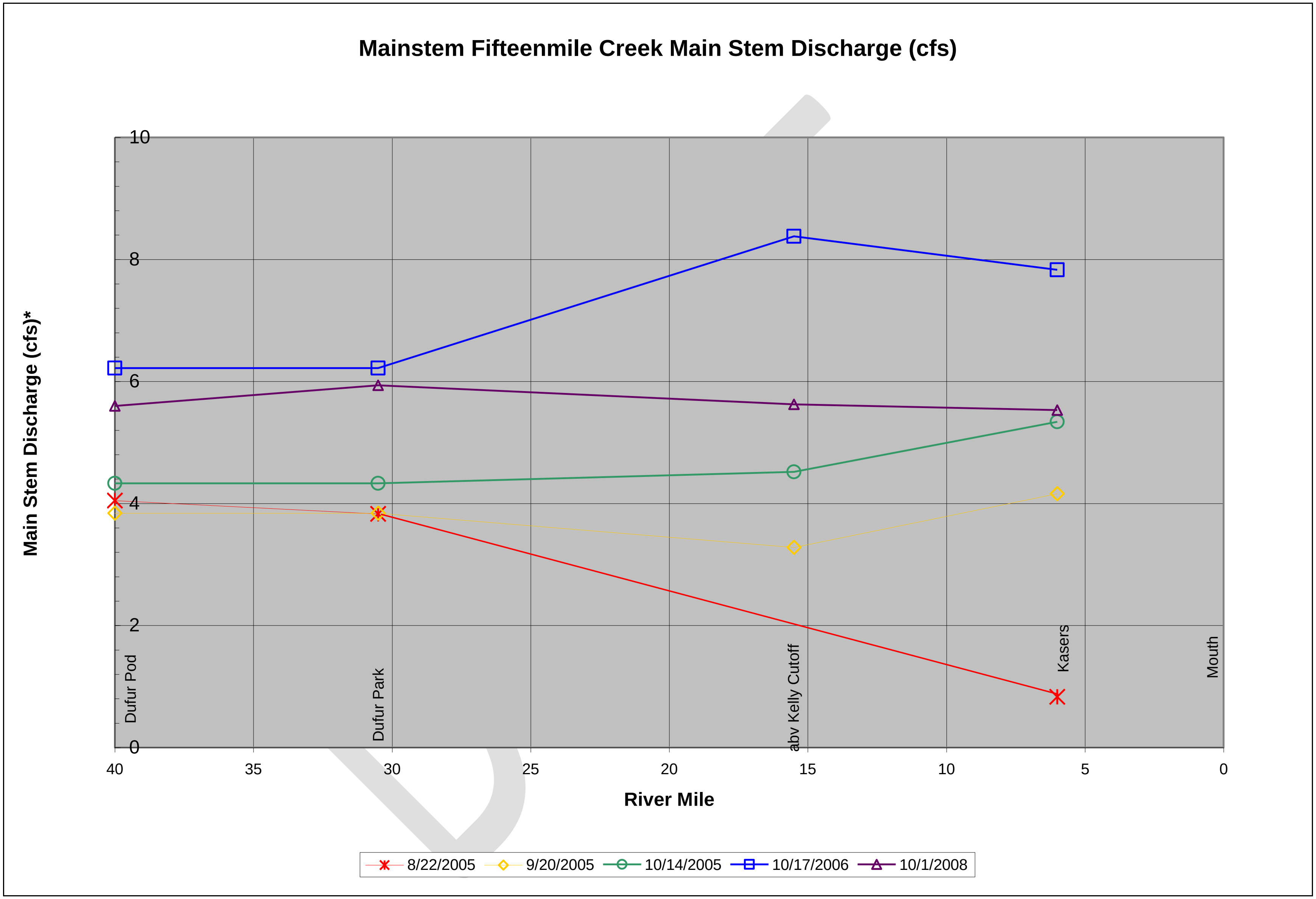


Figure 11: Filtered Results of District 3 Watermaster miscellaneous (synoptic) measurements. Only data when estimated withdrawals < 1.5 cfs and main stem flows (at Dufur POD) < 10 cfs are shown. * Main Stem Discharge = Measurement at Location + Upstream Diversions – Upstream Inflows (i.e., change in main stem flows due to GW/SW interactions).

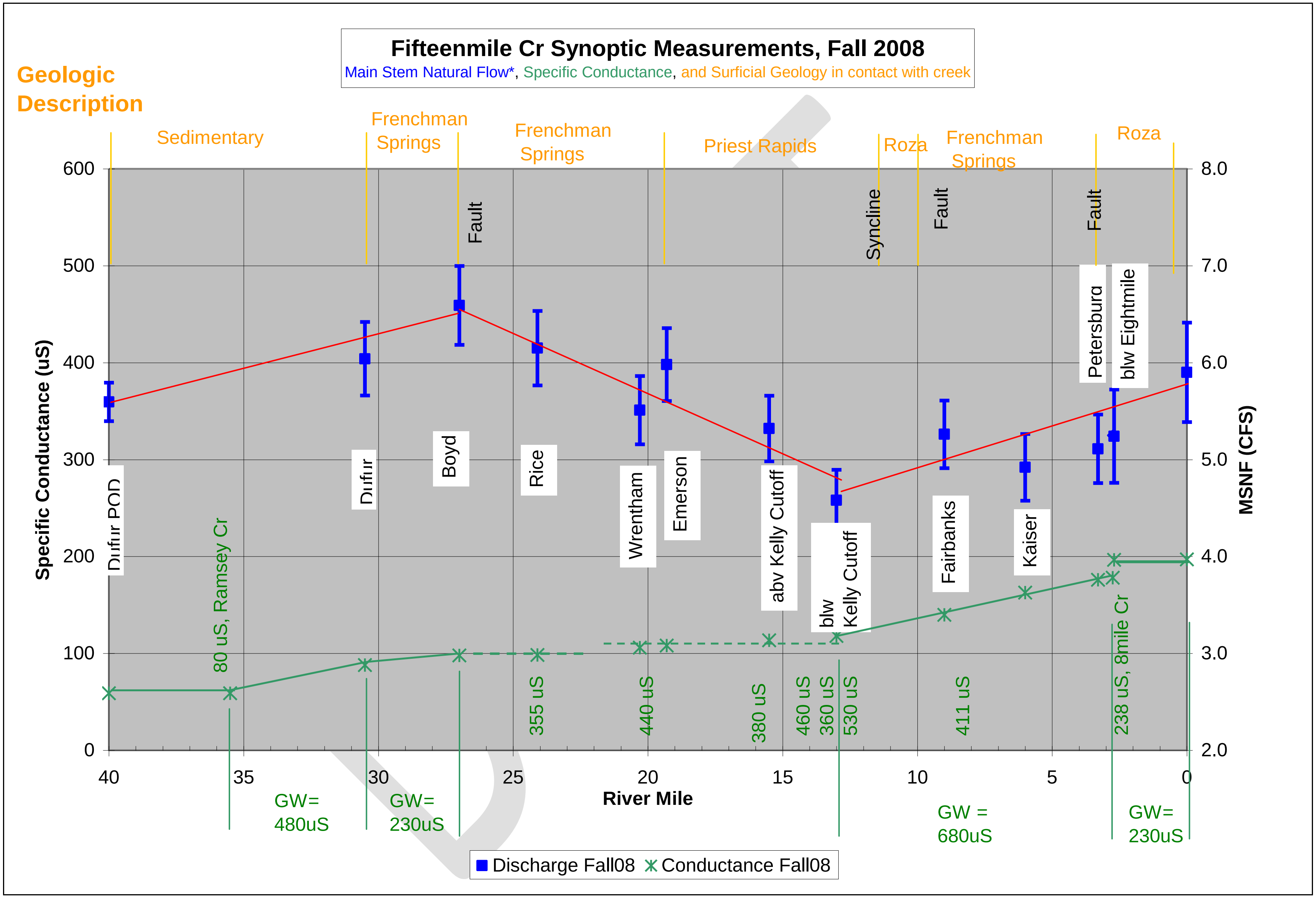


Figure 12: Fifteenmile Creek stream flow (blue), trends in stream flow red, specific conductance {SC} (green), sampled conductance on tributaries and springs (green text), derived groundwater SC (“GW =”, green text), and geologic contact with creek (orange).

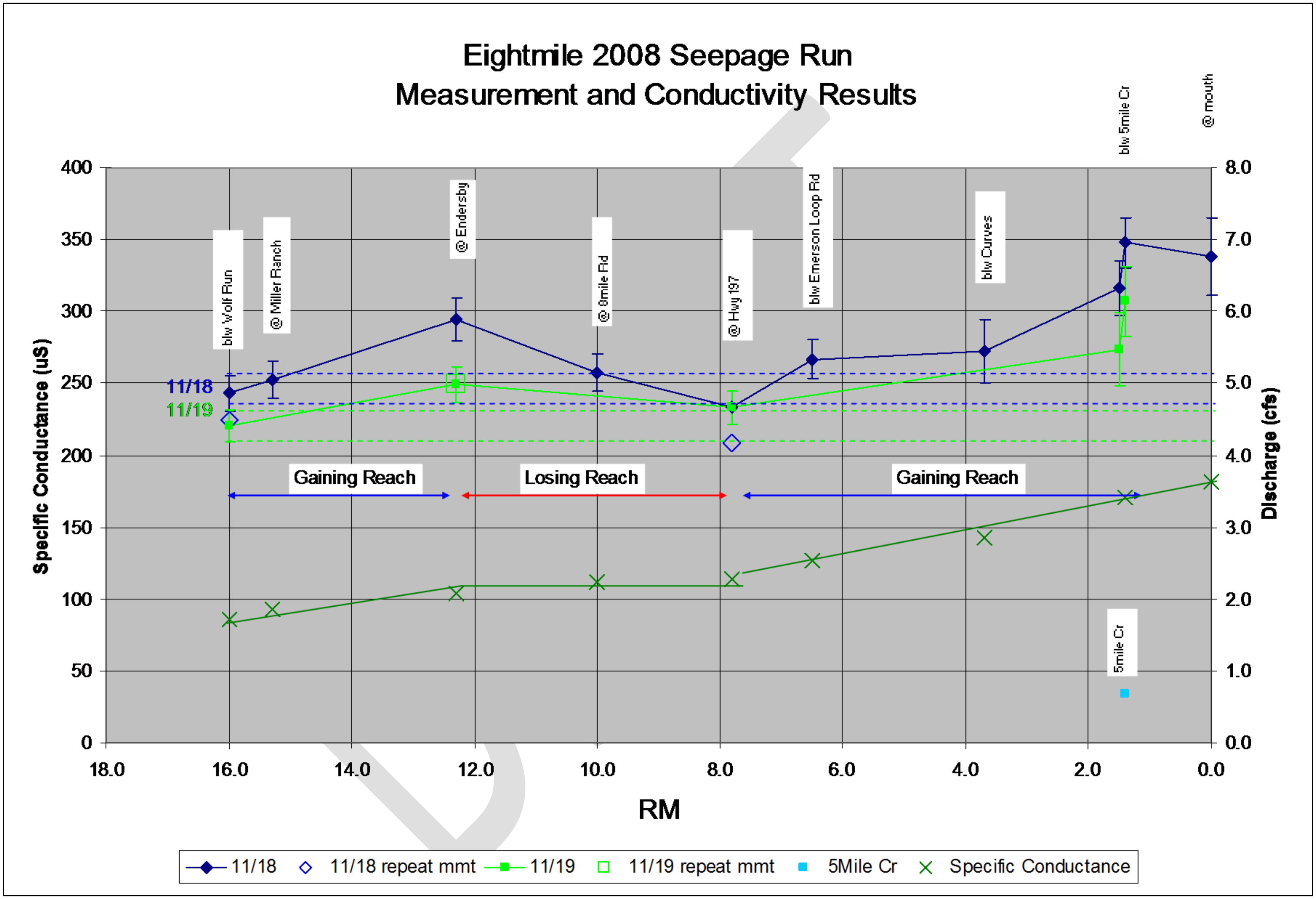


Figure 13: Eightmile Creek measurements. There were no diversions or inflows during the seepage runs, except for Fivemile Creek. The dashed lines represents inflow (+/- uncertainty) to the study area (i.e., RM 16). Check measurements are show in open squares or diamonds.

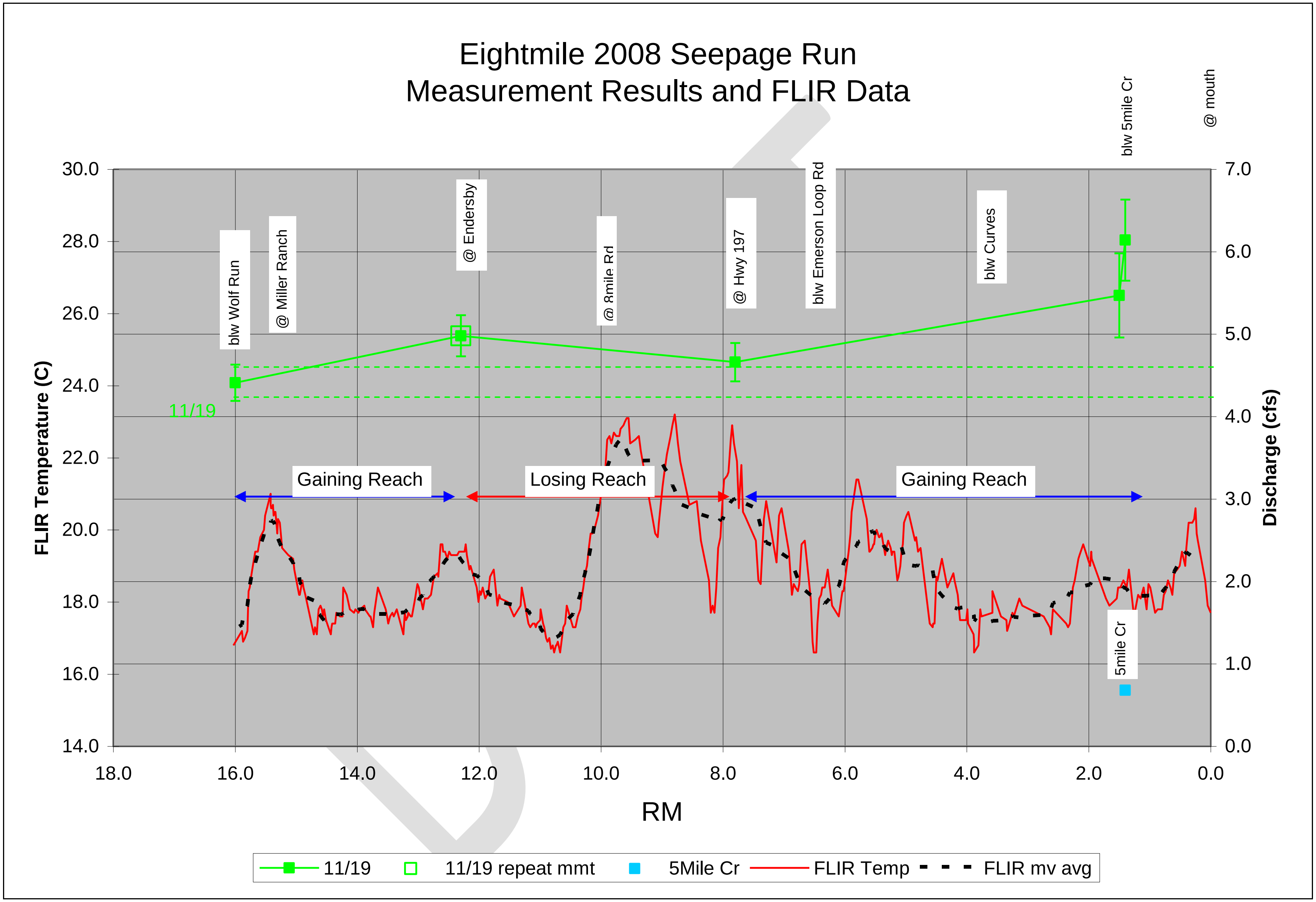


Figure 13: FLIR Stream Temperature Data and Reach Gain/Loss

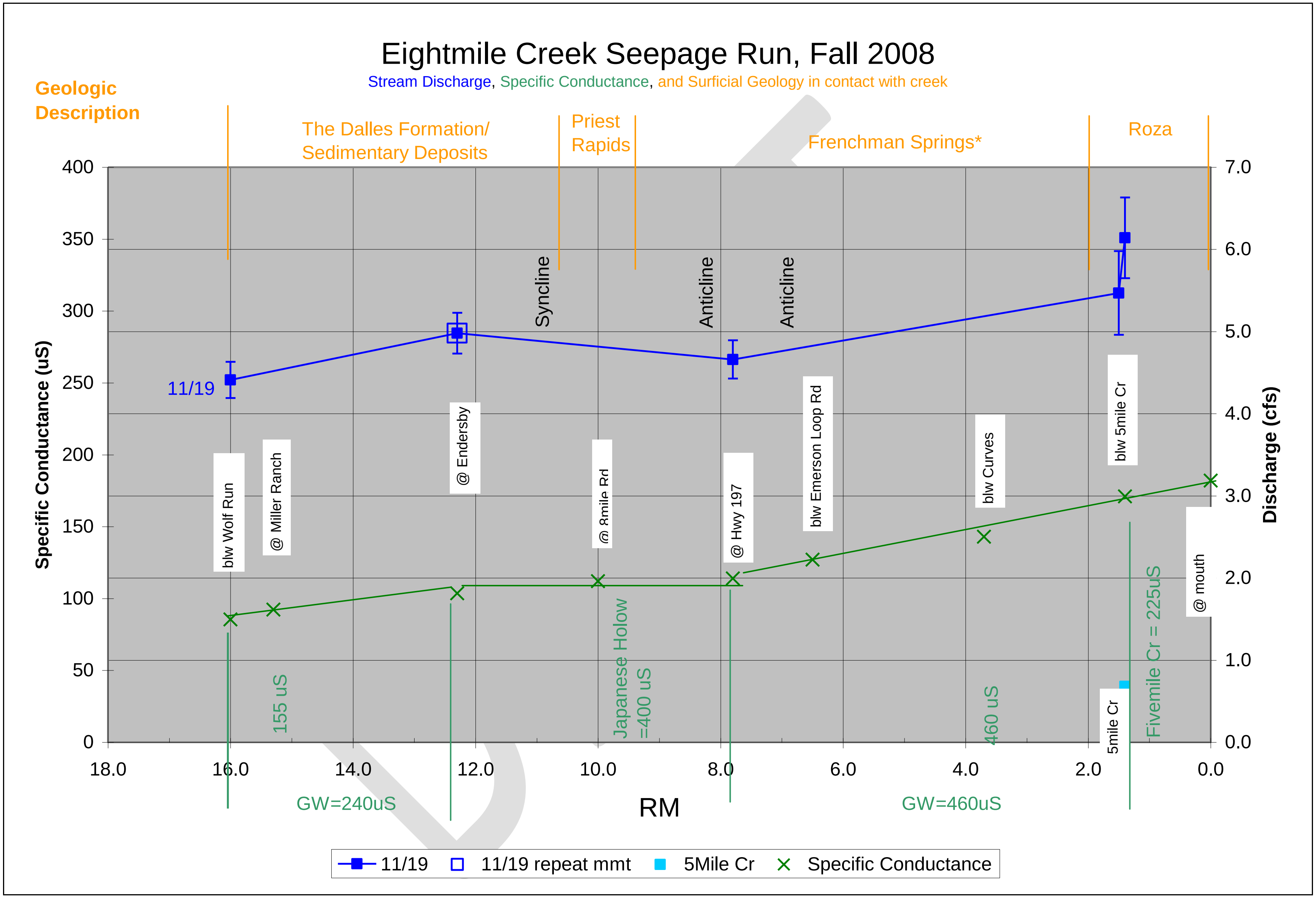


Figure 14: Eightmile Creek stream flow (blue), specific conductance {SC} (green), sampled conductance on tributaries and springs (green text), derived groundwater SC ("GW =", green text), and geologic contact with creek (orange).