DEARBORN WATERSHED

Water Supply and Water Use Study Report: 2007-2010

Montana Department of Natural Resources
DNRC Report: WR 2.D.7b Dearborn Watershed
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Introduction

The purpose of this report is to characterize the surface water hydrology and temperature regime of the Dearborn watershed. Beneficial water use within the watershed includes: agriculture, aquatic life, recreation and drinking water. During recent drought years, summer base flows have not been sufficient to meet all of these demands on the system. Montana Fish, Wildlife and Parks (FWP) identified the Dearborn River and its major tributaries as chronically dewatered (MFWP, 1991). In addition, high water temperatures and siltation are major impairments on the Dearborn River and its tributaries (MDEQ, 2002) resulting in inclusion on the TMDL 303(d) list. This project was initiated partially in response to concerns by the US Environmental Protection Agency (EPA) who recognized the need for further study of thermal modification before the Dearborn River and its tributaries could be removed from the Montana 303 (d) list (US EPA, 2005).

The project includes data collection and analysis for all major tributaries, from the Dearborn River's confluence with the Missouri River upstream to Falls Creek. Irrigated lands within the Dearborn River watershed were inventoried and used to estimate crop consumptive use. The study spanned four years (2007-2010) in an effort to capture normal, above average, and below average water years.

Goals

The specific objectives of this project are to: 1) characterize the surface water hydrology and temperature regime of the Dearborn River and its tributaries, and 2) identify major depletions of water including irrigation diversions and irrigated crop evapotranspiration.

The study also will improve the knowledge and understanding of the hydrology in the watershed and provides a basis for future work and TMDL implementation, if necessary. The information gathered will also benefit stakeholders by increasing awareness of potential water related problems and providing a first step toward examining potential water savings measures. The information gathered may lead to the improved overall health of the Dearborn River and a watershed fully supporting all beneficial uses.

Project Area

The study focused on the Dearborn River and major tributaries from its confluence with the Missouri River upstream to the headwaters just below Falls Creek, a reach of about 47 miles (Figure. 1). Above Falls Creek there are no major water withdrawals.

The headwaters of the Dearborn River originate in the Lewis and Clark Range of the Rocky Mountains along the east side of the Continental Divide. Approximately 48 square miles of the headwaters are located in the Lewis and Clark National Forest Scapegoat Wilderness area. Major Tributaries to the Dearborn River include the South Fork Dearborn River, Middle Fork Dearborn River, Falls Creek, Flat Creek and Sullivan Creek. The river flows generally to the southeast where it joins the Missouri River five miles northeast of Craig, Montana. The Dearborn River watershed covers approximately 550-square miles with the majority of the watershed located in Lewis and Clark County and a small portion in Cascade County.

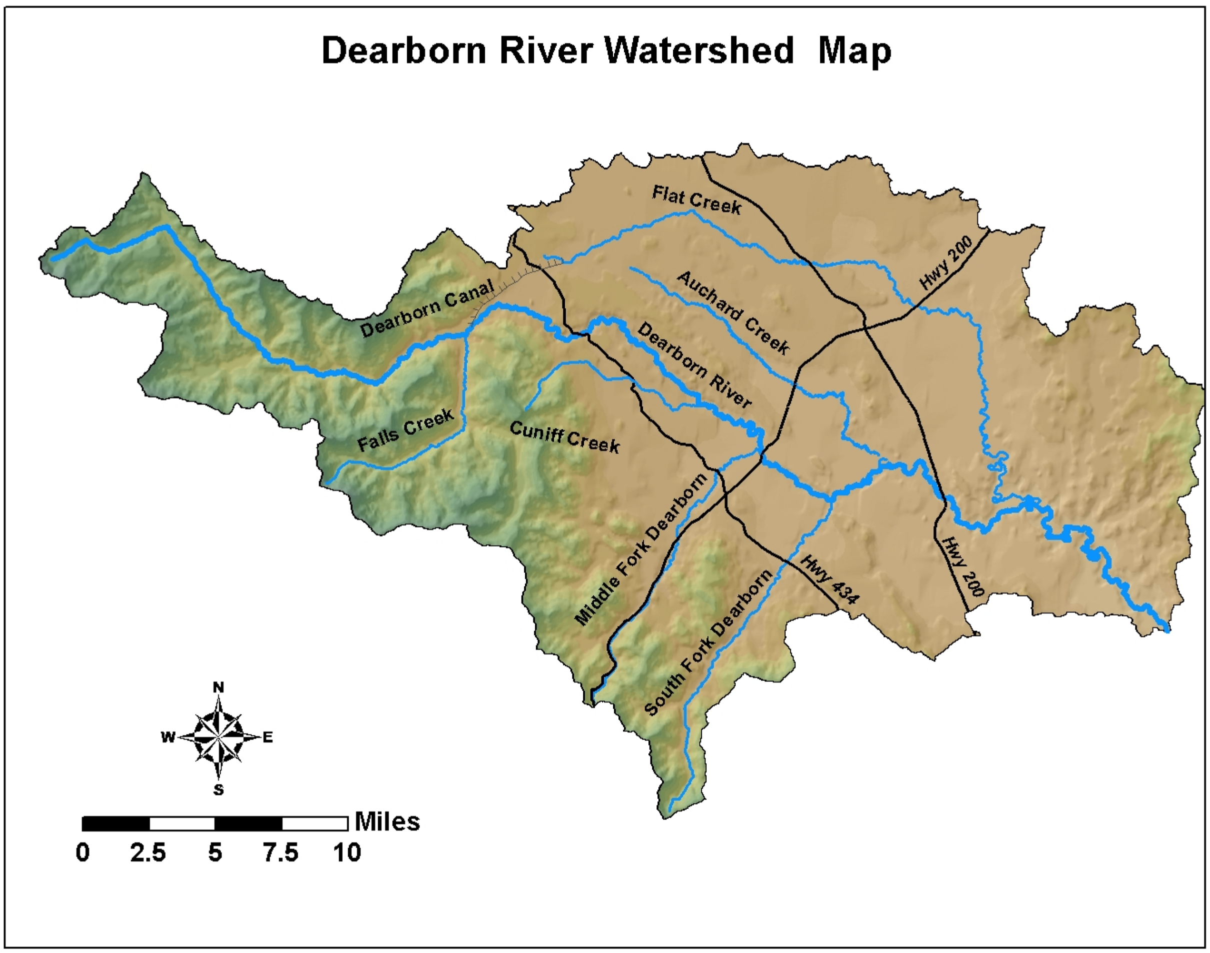

Figure 1: Dearborn River Watershed location map.

The Dearborn River is predominantly fed by snowmelt and rain during the spring and early summer months. River flows during the rest of the year are sustained by groundwater inflow and periodic runoff following rainfall events. Elevations in the watershed range from the 9,282 foot Scapegoat Peak in the headwaters, to a low of 3,449 feet at the confluence of the Dearborn and the Missouri Rivers. Average annual precipitation ranges from 13 inches in the lower elevations of the watershed to over 40 inches at the highest elevations, with the majority of the watershed receiving less than 19 inches (Figure 2; Daly and Taylor, 1998).

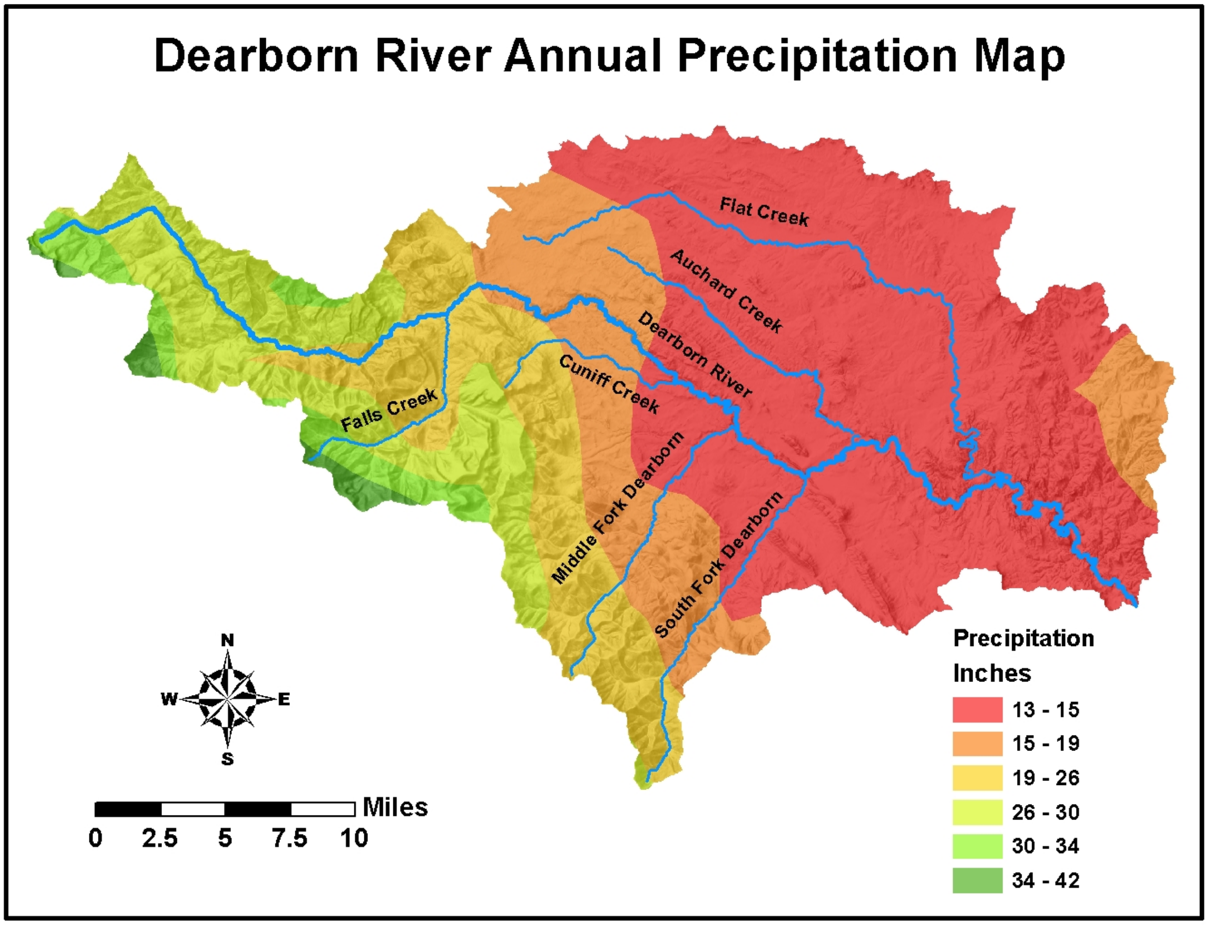

Figure 2: Precipitation map of the Dearborn River Watershed.

The most comprehensive record of precipitation over the study period was recorded at the Rogers Pass weather station, (Figure 3) (Montana Climate Office www.Climate.umt.edu)

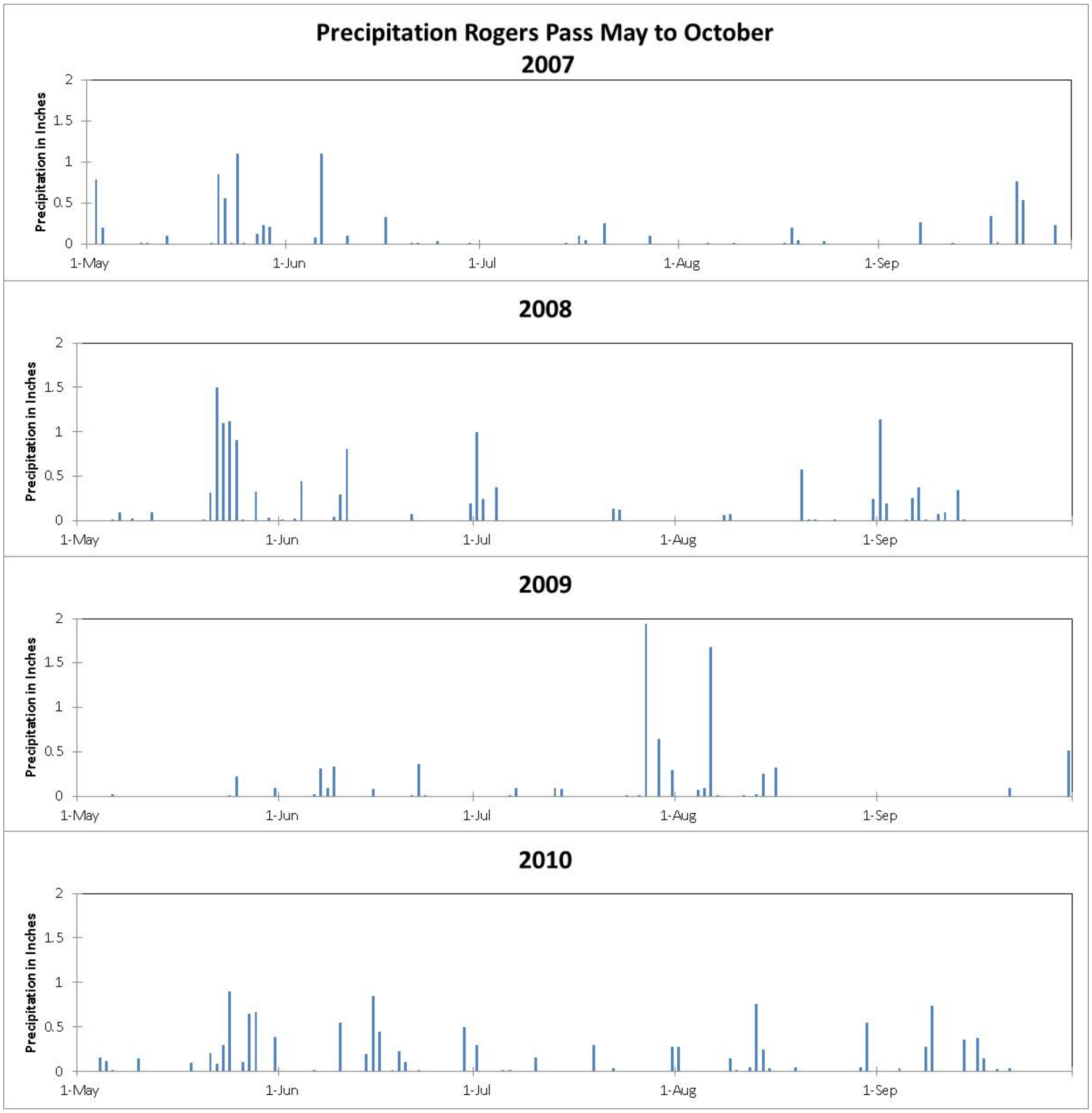

Figure 3: Precipitation recorded at Rogers Pass, Montana.

The mountainous headwaters of the Dearborn are located in an area of highly thrust faulted sedimentary rocks of the Proterozoic Belt Supergroup. Once the Dearborn River leaves the mountainous headwaters, the river enters complexly folded Cretaceous aged volcanic-rich sedimentary rocks (sandstones and shales) of the Two Medicine Formation and the Virgelle Sandstone member of the Eagle Sandstone. The Dearborn continues through Cretaceous-aged sedimentary rocks until reaching US Highway 287 where it enters the Adel Mountain Volcanics for the remainder of its 19 mile journey to the Missouri River. The riparian areas of the Dearborn River, South Fork of the Dearborn River, Middle Fork of the Dearborn River and Flat

Creek are composed of Holocene and Pleistocene-aged alluvial and colluvial deposits (Mudge and Others, 2001).

Glacial activity has played a major role in determining the current course of the Dearborn River. A piedmont glacier during the Pinedale age (approximately 25,000 years ago) diverted the Dearborn River from its historic course, now occupied by Flat Creek and caused the Dearborn River to incise its current channel out of bedrock (Foley, 1980). Glacial deposits can be seen in the Bean Lake area where the plains meet the mountains.

With the exception of the forested headwaters, the project area is primarily private land used for hay production, irrigated pasture and livestock grazing. There are approximately 6,200 acres of irrigated land within the watershed. The primary irrigation method in the watershed is flood irrigation. The majority of the irrigation in the watershed is along the Flat Creek with smaller amounts situated along the main stem Dearborn and tributaries. Currently no large irrigation water storage projects or significant inter-basin transfers of water exist.

The Dearborn Canal owned by the Dearborn Canal and Water Company is the largest irrigation diversion and canal in the Dearborn River watershed. The Dearborn Canal diverts water from the Dearborn River into the Flat Creek Drainage. Permission to gage the canal was not granted. The 1957 Lewis and Clark Water Resources Survey reported the capacity of the canal to be 100 cubic feet per second. The Dearborn Canal diversion works are located just below the confluence of the Dearborn River and Falls Creek.

Previous Investigations

At the outset of the study all available data, literature and maps related to the hydrology of the basin were compiled and reviewed. All existing and historic streamflow data were downloaded from the United State Geological Survey (USGS) database. Four USGS gages were identified, one current gage on the Dearborn River near Craig and three historical but discontinued gages on the Dearborn River near Clemons, the Dearborn River above Falls Creek near Clemons and Falls Creek near Clemons.

The Water Resources Survey of Lewis and Clark County published in 1957 (State Engineers Office) inventoried the history of land and water use in the Dearborn Watershed. Irrigated land and infrastructure are quantified and mapped in the document.

Montana Fish, Wildlife and Parks (FWP) identified the Dearborn River and its major tributaries as chronically dewatered in 1991 (MFWP, 1991).

The Dearborn River was listed by the Montana Department of Environmental Quality (DEQ) 303(d) as impaired for thermal modification (high water temperatures) and siltation in 1996 and 2002 (MDEQ, 2002). The major causes of impairment were identified as flow alteration and thermal modification of flow.

The United States Environmental Protection Agency (EPA) completed a Water Quality Assessment and Total Maximum Daily Loads (TMDLs) for the Dearborn River Planning Area (US EPA, 2005). This document identified the need for further study of thermal modification before the Dearborn River could be removed from the Montana 303(d) list.

The Dearborn River is classified by the State of Montana as a “B-1” water body, which intends for the waters to be “maintained suitable for drinking, culinary and food processing purposes after conventional treatment; bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply” (Montana Code ARM 17.30.623). Currently the Dearborn River is listed as fully supporting drinking water and agricultural uses. It is not supporting aquatic life and primary contact recreation due to impacts from hydrostructure flow regulation/modification and resulting water temperature.

Kean and Smith (2010) used the Dearborn River as a study reach to test a model-based approach to estimate stage-discharge relationships. Foley (1980), documented diversion and incision of the Dearborn River resulting from glaciation. Geologic mapping efforts in the area have been completed both by the Montana Bureau of Mines and Geology and the USGS (Mudge and Others, 2001). This is the first study that is a detailed investigation of the hydrology and water use characteristics of the Dearborn River watershed.

Methods

Streamflow Monitoring

The streamflow and temperature monitoring sites for this study were sited at seven key locations (Figure 4) throughout the watershed through a combination of in office research, driving publicly accessible roads and discussions with local landowners. GPS locations of DNRC gages are presented in Appendix A.

Each gaging site consisted of a stilling well, staff gage and a water level logger. Stilling wells were constructed using a perforated 10 foot long, 2 inch diameter galvanized steel pipe, with a welded drive point and a locking cap. A staff gage was mounted on the outside of the stilling well. A capacitance-type water level logger (Tru Track WT-HR or AquaRod Water Level and Temperature Logger) was installed inside the stilling well and was set to record stage at 30 minute intervals. The elevation of the stilling well was surveyed in place using a laser level, allowing field staff to check for staff gage and casing movement between visits. GPS locations were recorded for each gaging site.

Field visits were conducted about once a month from May through October. During each visit, the staff gage was read manually, data were downloaded from the water level recorder and stream discharge was measured. Other field observations concerning the gaging pool control, flow conditions, and weather were recorded.

Discharge measurements followed standard USGS methodology (Nolan and Others, 2000) using either a Marsh-McBirney FlowMate® Model 2000 Flow Meter or a Sontek FlowTracker®. High flow measurements were made at some of the gages using bridge equipment or an acoustic-Doppler measuring device.

Synoptic streamflow measurements determined gains and losses in the mainstem of the Dearborn River. Synoptic flow measurements provide a snapshot of flow conditions at a particular time by measuring discharge at a number of locations along a river and tributaries during a period of stable discharge typically during the same day.

Surface water losses are assumed to result from diversions or seepage of surface water to groundwater and gains are due to groundwater discharging back to the surface water or ungagged tributaries. Surface water diverted from the Dearborn River was not directly quantified during by synoptic measurements. River reaches where diversions were present were noted during the synoptic runs. Surface evaporative loss was assumed to be negligible over the measurement period. Gains and losses associated with tributary inflow or groundwater interactions were calculated using the following equation:

Gain/Loss = (ΣBasin Outflows – ΣBasin Inflows)

Temperature Monitoring Network

Temperature monitoring was conducted at all stream monitoring sites during the study period in order to characterize the thermal regime of the system. Temperature has been demonstrated as an effective tracer to estimate hydraulic properties of streambeds and near surface groundwater (Stonestrom and Constantz, 2003). Temperature sensors were installed at multiple depths below the streambed to examine near surface hydraulic properties.

Surface water and streambed water temperatures were recorded hourly at each stream gaging site during 2007 and 2008. Streambed temperature monitoring was conducted by attaching three Onset StowAway® Temperature loggers to a 4-foot piece of PVC pipe. The PVC pipe and temperature loggers were inserted into the stilling well with the loggers attached at the following depths: 0 feet (ft), 1.5 ft and 4 ft below the stream bed surface. The temperature loggers were not vertically isolated during the study. Surface water temperature was recorded using either an Onset Hobo® temperature logger or the temperature logging capabilities of the water level recorder.

Manual surface water temperature measurements were made with a thermometer during initial deployment of temperature loggers and during each site visit. Manual measurements were used as a check to ensure the loggers were functioning correctly.

Irrigated Lands and Evapotranspiration

Irrigation in the watershed was mapped and characterized in Geographic Information System (GIS). This included identifying (1) irrigated lands, (2) the types of irrigation systems used and (3) the ditches and water sources that supplied the irrigated lands.

Irrigated lands were mapped in detail by the State Engineers Office (Lewis and Clark County Water Resources Survey (WRS), 1957). This information was later digitized as a layer in GIS by the DNRC.

The WRS identified irrigated lands and ditches were found to be relatively accurate, however land use has changed in the more than five decades since the Water Resource Surveys (WRS) have been completed.

Irrigated lands were mapped by the Montana Department of Revenue Final Lands Unit (FLU) in 2005 and 2009 for purposes of taxation. The FLU data are from a GIS data layer identifying irrigated lands by application type, such as flood, sprinkler and pivot.

Inconsistencies between the WRS and FLU data sets and changes over time led DNRC personnel to hand digitize irrigated lands to better map the current extent of irrigation. Irrigated lands were delineated at a 1:6,000 scale in ArcGIS, using natural color (red, green and blue) and near-infrared imagery acquired from the United States Department of Agriculture's (USDA) National Agriculture Imagery Program (NAIP) (USDA, 2007).

NAIP imagery for the years 2005, 2009 and 2011 were examined to delineate irrigated lands at a field scale. Once a field was determined to be irrigated, a digital boundary was drawn around the field and the acreage was quantified in GIS. The field was assigned attribute properties of irrigation method and crop type. Irrigated lands were spot checked from publically accessible roads for accuracy. Additional information about the DNRC irrigated lands delineation process can be found in Appendix B.

Consumptive use of irrigation water was estimated using the following two methods: (1) Estimating Dearborn Canal diversion and consumption based on gaged Dearborn River and Flat Creek flows, (2) using remote sensing and mapping of irrigated acres in GIS to estimate evapotranspiration (ET) for 2007.

Dearborn Canal diversion volumes were estimated using three DNRC stream gages. Indirect measurement of the diversion added uncertainty to this method. Depletions were calculated using diversion estimates and flow data from Flat Creek.

Estimating evapotranspiration (ET) using remote sensing requires: (1) the quantification of irrigated acreage, (2) compilation of monthly near infrared scenes from LandSat (USGS and NASA, 2007) over the 2007 irrigation season (LandSat resolution is 30 x 30 meter), (3) local weather information from an AgriMet station (U.S Bureau of Reclamation 2007) and (4) an automated program to estimate ET for pixels in the delineated irrigation polygons based on local weather information and thermal band infrared (IR) signals from LandSat.

Resources were only available to calculate ET using remote sensing for 2007. For all estimation methods, ET is presented at a drainage scale rather than a field scale. See Appendix C for a more detailed description of the remote sensing methodology.

Data Analysis

Stream stage and discharge relationships were developed using the Aquatic Informatics Aquarius® Rating Curve program. Rating equations were used to convert the 30-minute water stage data into discharge and then these were summarized as daily average stream flow. Daily average flows and discharge measurement results have been archived in an internal DNRC database.

Stream and streambed temperatures were reduced to daily average, minimum and maximum temperatures. In addition, temperature results were compared to cold water fisheries temperature metrics to assess when cold water aquatic species growth guidelines and lethal thresholds were exceeded. Temperature data collected by the DNRC was submitted to the DEQ for archive.

During the study period, some streamflow and temperature data were lost due to flooding or equipment malfunction. Missing data was estimated using simple linear regression or through simple addition of known flows. Regressions were typically built between the USGS Highway 287 streamflow gaging station and the station with missing data. It was found that regression equations achieved the best results when bounded by flow conditions such as spring base flow, runoff and fall base flow. With the exception of the gage at the mouth of the Dearborn River, all missing data were reconstructed using regression equations and checked for accuracy using known flows. Missing data for the Dearborn River at the mouth station was filled in using the data from the USGS gage at Highway 287 station plus measured outflows from Flat Creek to the Dearborn River.

Flat Creek inflows above the Dearborn Canal discharge point were not measured. Most of the water in Flat Creek during the irrigation season is typically diverted water from the Dearborn River. Natural inflows to Flat Creek were estimated using regression equations specific to the Dearborn Drainage developed by the DNRC based on measured flows, median drainage elevation and drainage area.

Stream Gaging Stations

In April 2007, the DNRC installed seven stream flow gages for this study (Figure 4). The gages were seasonal and generally operated during May through October. Three gages were installed on the mainstem of the Dearborn River. The uppermost gage (Upper Dearborn) on the Dearborn River was located just below the confluence of Falls Creek and is representative of natural inflows to the watershed. The Dearborn Canal Company head gate, which is the most significant irrigation diversion on the Dearborn River, is located just below the gage. The Highway 200 Bridge gage is located approximately 16 river miles downstream of the Upper Dearborn gage, just downstream of the confluence of the Middle Fork Dearborn River. The Dearborn Mouth gage is the lower most gage on the Dearborn River and monitors water exiting the watershed. It is about 30 miles downstream of the Highway 200 Bridge and approximately 300 yards above the confluence with the Missouri River.

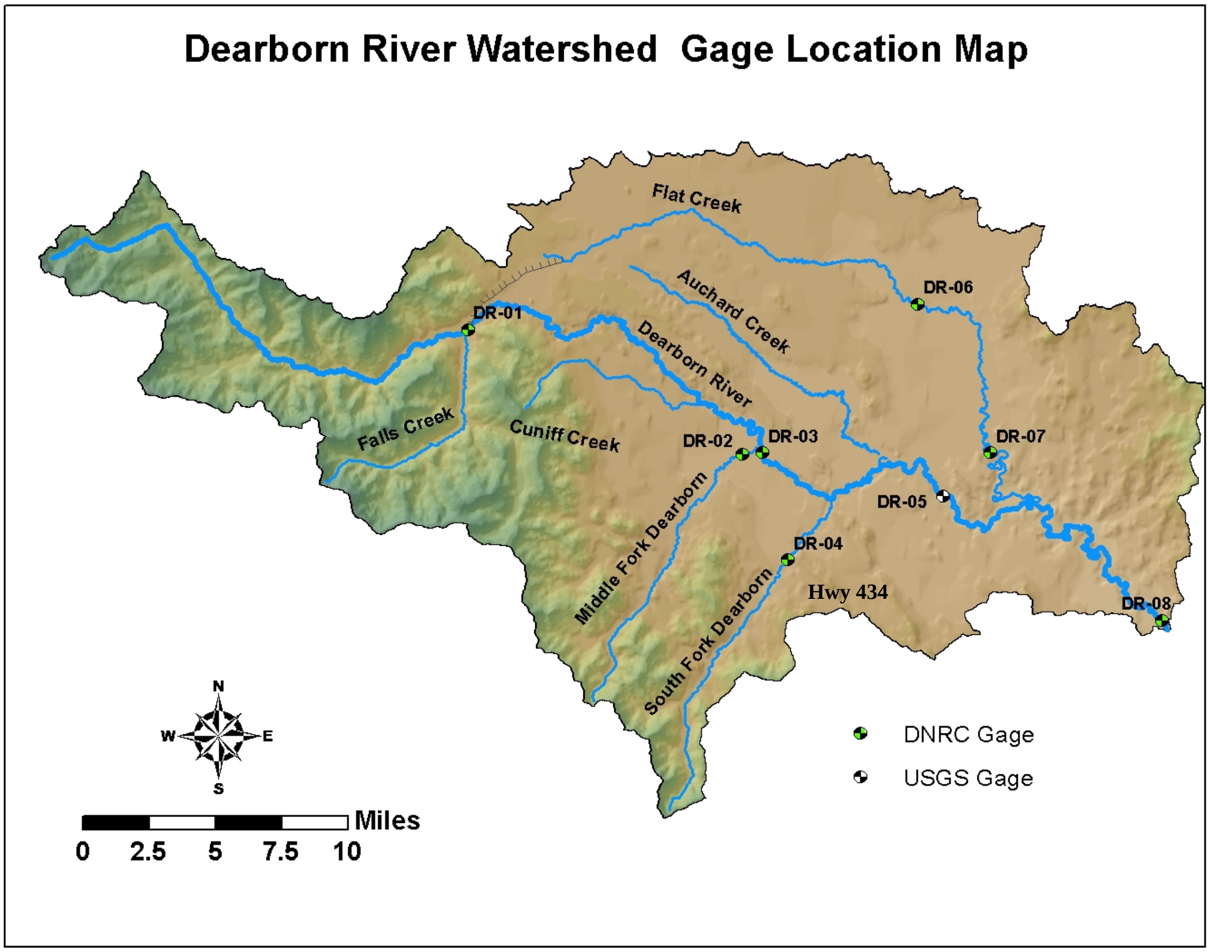

Figure 4: Dearborn Watershed and stream gaging station location map.

Gages were also installed on the Middle Fork, South Fork and Flat Creek to measure tributary inflows to the Dearborn River. The Middle Fork gage was located approximately 100 yards upstream of the confluence with the Dearborn River near Highway 200. The South Fork gage was installed just downstream of the Highway 434 crossing. Two gages were located on Flat Creek; the upper most gage was located on the downstream side of the Highway 200 crossing and the lower Flat Creek gage (Flat Creek Canyon) was located approximately 2 miles south of the Birdtail Road crossing, near where Flat Creek enters the Adel Mountain Volcanics. Dearborn watershed gaging locations are summarized in Table 1.

Station Name	Identifier	Operator	Drainage area above Gage (mi^2)	Approximate Acres Irrigated Upstream
Upper Dearborn	DR-01	DNRC	110	0
Middle Fork Dearborn	DR-03	DNRC	68	475
Dearborn Hwy 200	DR-02	DNRC	255	4,112
South Fork Dearborn	DR-04	DNRC	46	566
Dearborn near Craig (6073500)	DR-05	USGS	325	4,426
Flat Creek Hwy 200	DR-06	DNRC	85	3,277
Flat Creek Canyon	DR-07	DNRC	135	4,045
Dearborn Mouth	DR-08	DNRC	550	6,220

Table 1: Dearborn Watershed Gaging Stations (irrigated acres listed at Dearborn Highway 200, Dearborn Craig and Dearborn Mouth include irrigated acres in the Flat Creek Drainage)

The USGS maintains a streamflow gaging site located upstream of the Highway 287 Bridge that has been continuously operated from 1946 – 1969 and from 1993 – present. The USGS gaging site is located 10 miles downstream of the DNRC Highway 200 gaging site. This gage captures the flows of all the perennial tributaries of the Dearborn River except for Flat Creek.

The USGS operated three historic but discontinued gages on the Dearborn River:

- USGS gage 6073000, Dearborn River near Clemons, MT, active April 1, 1921 through September 30, 1953. Located below the Dearborn canal diversion.
- USGS gage 6072000, Dearborn River above Falls Creek, active May 5, 1908 through December 31, 1911.
- USGS gage 6072500, Falls Creek near Clemons, active April 1, 1921 to September 30, 1959.

Dearborn River Watershed Streamflow Characteristics by Subbasin and Stream Reach

Upper Dearborn River

Upper Dearborn River below Falls Creek and DRNC gaging station

The Upper Dearborn gage is located above all major irrigation withdrawals and is representative of most natural inflows into the watershed. The drainage area is approximately 110 square miles and the median elevation of land above the Upper Dearborn site is 6,339 feet. Irrigated lands are not present above the gage. A seasonal hydrograph of daily average flows at this site illustrates seasonal peaks and baseflow (Figure 5).

The hydrograph in early May, prior to runoff, varies in magnitude from year to year. Pre-runoff flows are largely affected by the melting low (below 5,000 ft) and mid-elevation (below 6,500 ft) snowmelt and precipitation. Runoff hydrographs are also variable from year to year and not always predicated on pre-runoff flows. For example, although the 2008 and 2010 pre-runoff flow conditions are very similar, the snowpacks and precipitation patterns during those years are substantially different.

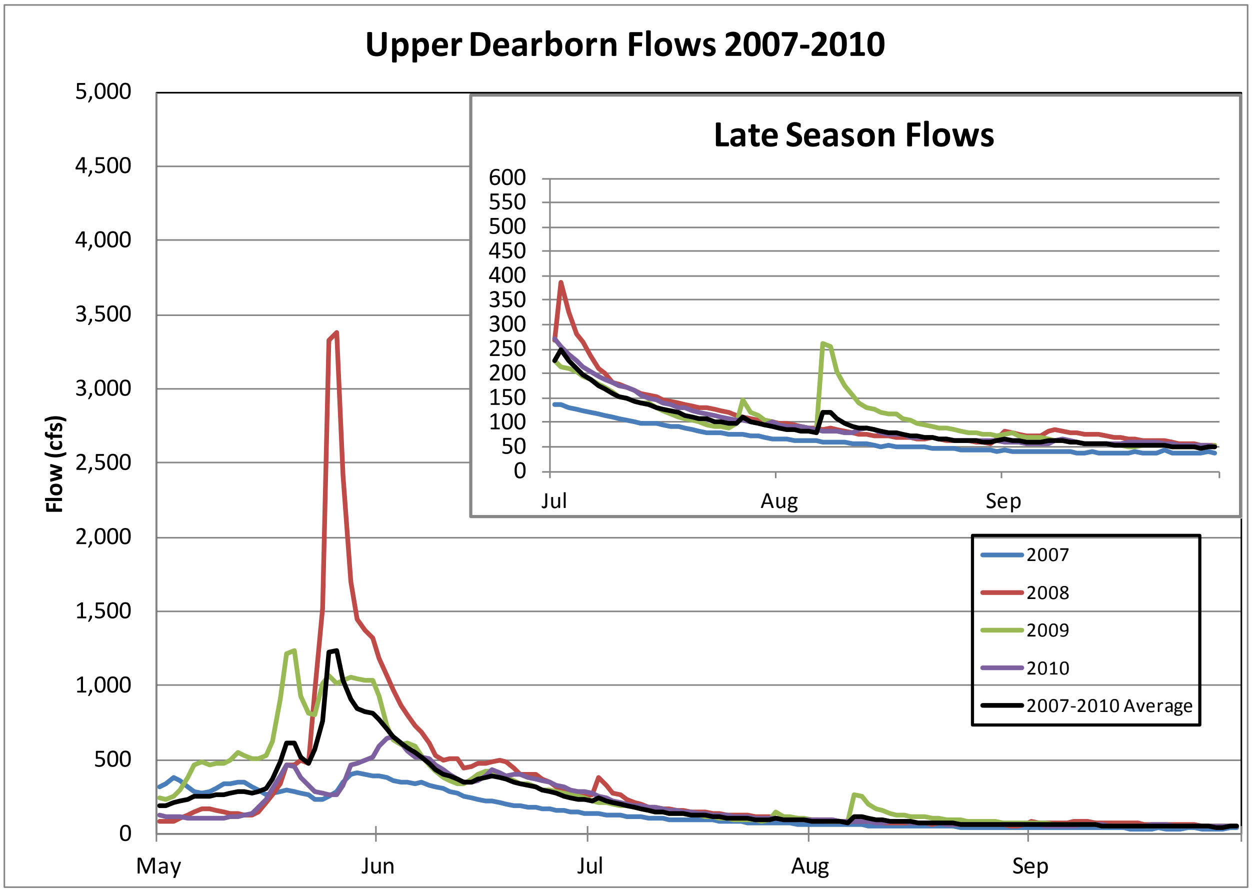

Figure 5: Hydrograph of the Upper Dearborn site 2007-2010. The inset hydrograph depicts flows during the summer and early fall.

During the study period flow in the Dearborn River peaks in late May and then flows drop off quickly as the high elevation headwaters snowpack is depleted towards the end of June. During the study period the highest daily peak flow of 3,375 cubic feet per second (cfs) was estimated on May 26, 2008. The lowest yearly daily peak flow of 410 cfs was recorded on May 29, 2007; the average of daily peak flow is estimated at 1,235 cfs.

The high flows observed in May 2008 were caused by a rain on snow event that occurred on May 26, 2008, where approximately five inches of rain fell in the watershed over a five day period (Figure 3). This rain event created a peak crest at the USGS Highway 287 gage of 5,150 cfs which was computed as having 5% exceedance interval (a 20-year flood). Flows shown in the graph (> 450 cfs) exceed the limits of the rating curve for this station and are an estimate.

Following the peak in late May, flows at the upper Dearborn gage steadily declined and reached typical low conditions by mid-July. During the study period, late season flows (August-September) averaged 68 cfs, with the lowest flow of 36 cfs recorded on September 7, 2007. Surface water flows generally decrease into September at which time the lowest discharges over the measuring season were observed. Spikes in the hydrograph, observed in July and August of 2008 and 2009 are a response to localized convective storms.

The highest flow volumes were observed during runoff in May and June (Figure 6). Flow volumes dropped substantially in July, coinciding with the end of runoff and the beginning of summertime low flows. The volume of water at the Upper Dearborn site during runoff (May through July) averaged 71,508 acre feet (af) during the study, with a high of 94,893 af (2008) and a low of 45,652 af (2007). Peak flow volumes in May and June tended to be more variable from year-to-year than low flow volumes.

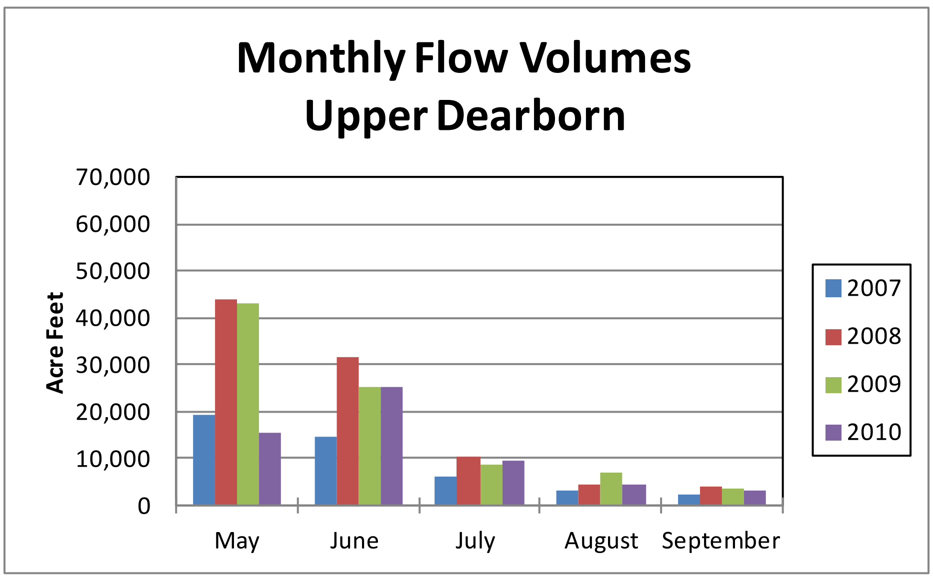

Figure 6: Monthly flow volumes at the Upper Dearborn site.

Dearborn Highway 200

Dearborn River below Highway 200 and DRNC gaging station

The Highway 200 gage is about 16 miles downstream and the first gaging site on the Dearborn River below the Dearborn Canal Company Canal. The recorded flow at the Highway 200 station is representative of conditions in the middle reach of the river and includes the effects of water diverted from the river, in addition to inflow from the Middle Fork and Cuniff Creek. The drainage area of the Dearborn River (including the Middle Fork) at Highway 200 is approximately 255 square miles. The median elevation of lands above the Highway 200 gage is 5,989 ft.

The hydrograph of the Dearborn River at Highway 200 (Figure 7) is slightly larger in magnitude during runoff than conditions found at the Upper Dearborn site because of the increased drainage area and additional flows from Middle Fork and Cuniff Creek. Late season flows are typically lower due to diversions by the Dearborn Canal. Variability in pre-runoff flows and the timing and duration of peak flows in late May/early June mimic conditions found upstream at the Upper Dearborn site.

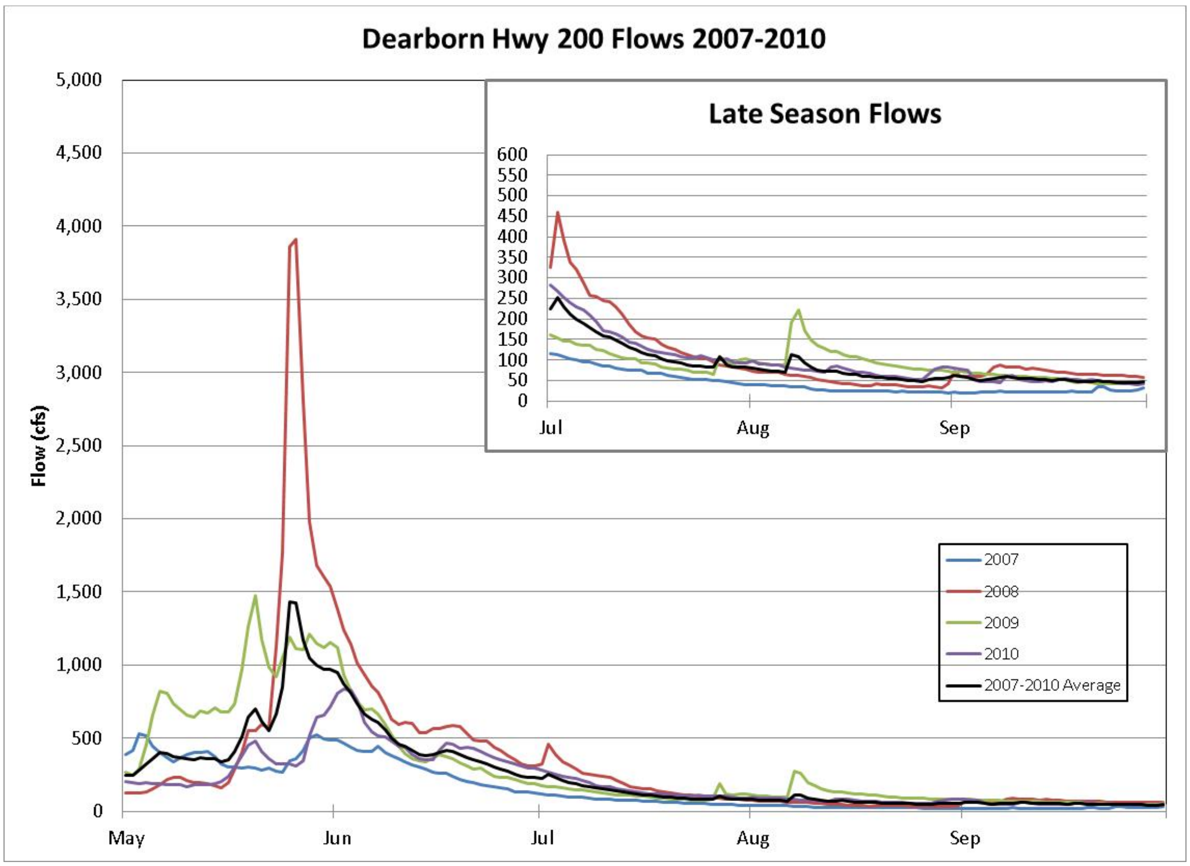

Figure 7: Hydrograph of the Dearborn at Highway 200 site 2007-2010.

During the study period, the highest daily average peak flow of 3,913 cfs was recorded on May 26, 2008 with the lowest daily average peak flow recorded on May 3, 2007 at 531 cfs. The average of daily peak flows is 1,430 cfs. The peak flows (> 560 cfs) shown in the graph for the Highway 200 Dearborn site are estimated and exceed the limits of the rating curve for this station.

Low flow conditions at the Highway 200 site typically start in mid-July. During the study period late season flows (August-September) averaged 60 cfs. Surface water flows generally decrease into September when the lowest discharges were observed. The lowest discharge measured at this site was 20 cfs was on September 3, 2007 as compared to 36 cfs measured at the Upper

Dearborn site on September 14, 2007. Not only is the lowest discharge less at the Highway 200 site but it also occurs earlier. The Highway 200 site had an 8 cfs decrease in average late season (August to September) flows when compared to Upper Dearborn site. Spikes in the hydrograph observed in July and August of 2008 and 2009 are a response to localized convective storms.

The highest flow volumes were observed in May and June at the Dearborn Highway 200 site (Figure 8). Flow volumes dropped dramatically in July coinciding with the end of runoff and the period of summertime low flows. Higher flow volumes at the Highway 200 site reflect the addition of water from the Middle Fork of the Dearborn River and Cuniff Creek. Depletions due to irrigation diversion contribute to lower flow volumes in July, August and September.
The volume of water passing through the Highway 200 site during runoff (May through July) averaged 78,955 af during the study with a high of 107,980 af in 2008 and a low of 47,746 af in 2007.

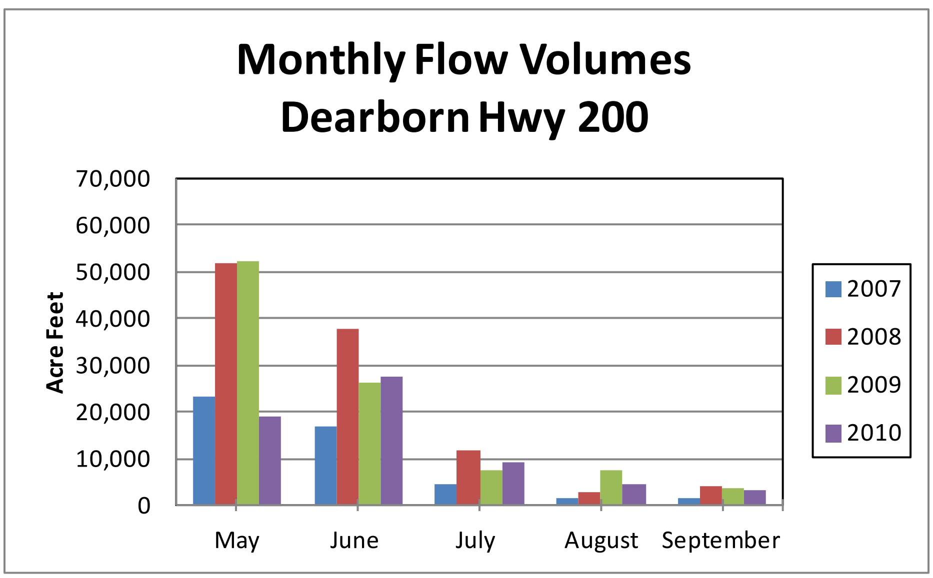

Figure 8: Monthly flow volumes at the Dearborn Highway 200 site.

Dearborn Mouth

Dearborn River near the mouth and DRNC gaging station

The Dearborn Mouth site is located near the confluence of the Dearborn and Missouri Rivers (Figure 2). Flows measured at this site are representative watershed outflows. The drainage area of the Dearborn River at the mouth is approximately 550 square miles with a median elevation of lands above the site at 4,899 ft. Approximately 6,220 acres are irrigated above the Dearborn Mouth site.

The hydrograph of the Dearborn River at the mouth (Figure 9) is larger in magnitude than conditions found at the Highway 200 and Upper Dearborn sites. Variability in pre-runoff flows and the timing and duration of peak flows in late May/early June mimics conditions found elsewhere on the Dearborn River. Peak flows were observed to quickly drop as the snowpack in the headwaters was depleted.

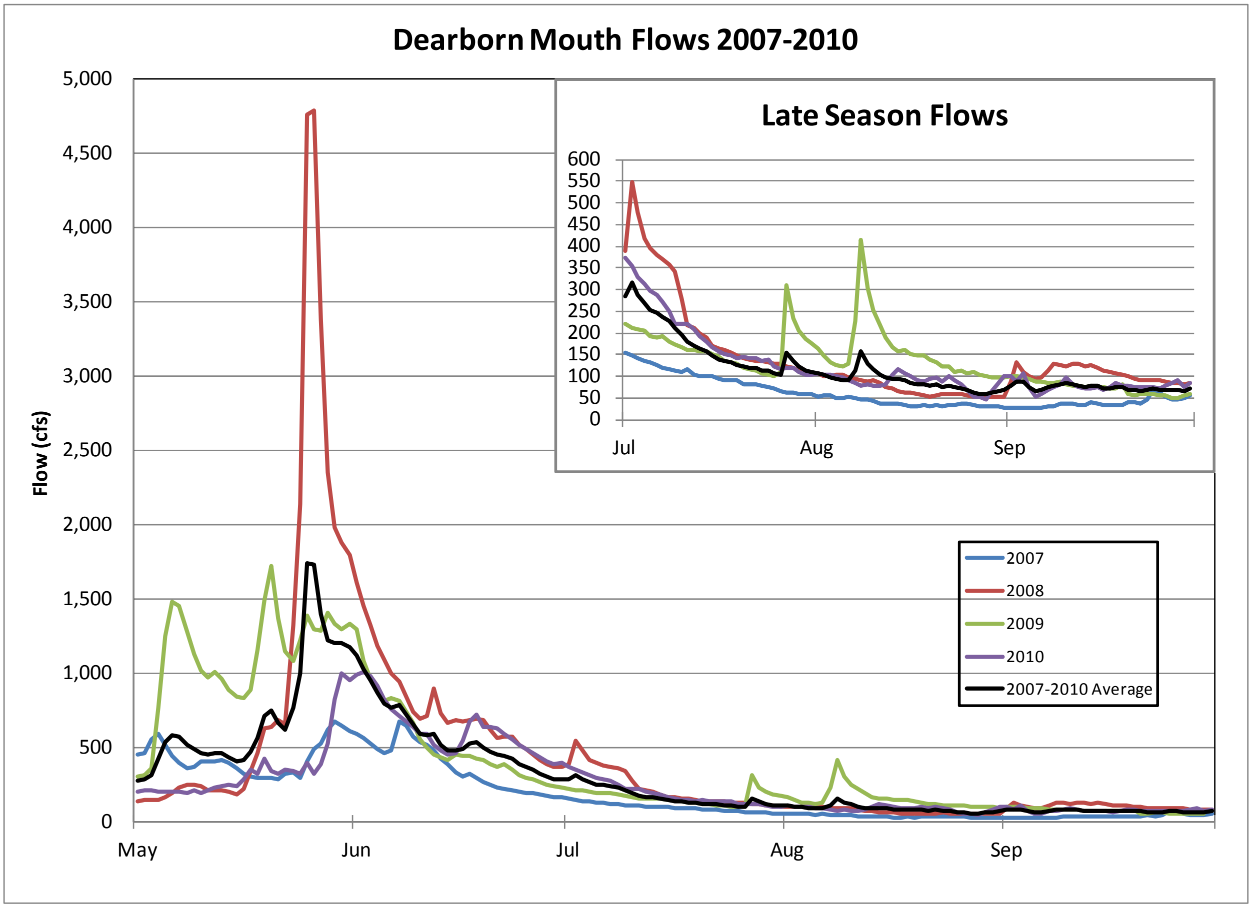

Figure 9: Hydrograph of the Dearborn Mouth site 2007-2010.

Flow volumes and peak discharges at the mouth increased as expected with the additional flows from tributaries and from Flat Creek, which is mostly composed of diverted water from the Dearborn. During the study period the highest daily average peak flow of 4,790 cfs was estimated on May 26, 2008 and the lowest daily average peak flow was recorded on May 29, 2007 at 671 cfs. Average of daily peak flow is 1,738 cfs. Peak flows (> 1,000 cfs) shown in the graph are estimated and exceeds the limits of the rating curve for this station.

Low flow conditions at the Dearborn Mouth site start in mid-July. Late season flows (August-September) averaged 81 cfs over the study period. Surface water flows decrease in September when the lowest discharges are observed. The lowest discharge measured at this site was 27 cfs (August 31-September 1, 2007). Unlike the other gages on the mainstem of the Dearborn, return flows from irrigation in the Flat Creek drainage are evident in most years as stream discharge increases in early to mid-September.

Depletions in late season flows are evident at the Dearborn Mouth station with an earlier and lower "low" flow of 27 cfs (August 31, 2007), compared to 36 cfs (September 14, 2007) at the uppermost Dearborn River site. The additional inflow of tributaries increased the volume of the lowest “low” flow at the Dearborn Mouth by 7 cfs as compared to the Highway 200 site (20 cfs). Average late season flows (August-September) at the Dearborn Mouth site increased by 13 and 21 cfs relative to the Upper Dearborn and Highway 200 sites respectively. Spikes in the hydrograph are observed in July and August of 2008 and 2009 and are most a response to localized convective storms.

The highest flow volumes were observed in May and June during the study (Figure 10). Flow volumes at the Dearborn Mouth site were the highest observed of all the Dearborn River gaging sites due to the addition from the Middle Fork, South Fork and Flat Creek. Depletions due to irrigation diversion contribute to lower flow volumes in July, August and September. Flow volumes dropped dramatically in July coinciding with the end of runoff and of the beginning of summertime low flows. The volume of water passing through the Dearborn Mouth site during runoff (May through July) averaged 98,346 af during the study with a high of 130,798 af in 2008 and a low of 58,817 af in 2007.

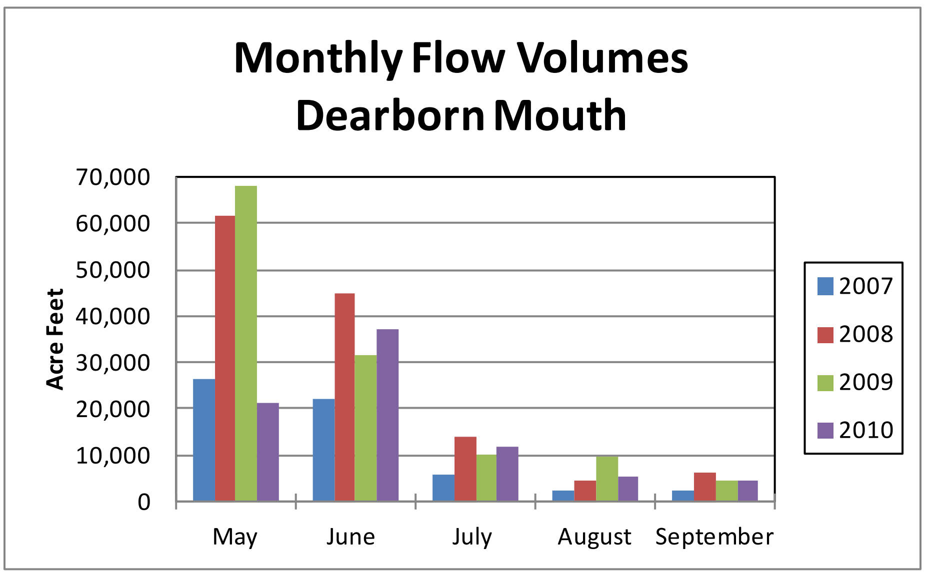

Figure 10: Monthly flow volumes at the Dearborn Mouth site.

Middle Fork Dearborn

Middle Fork of the Dearborn River above the confluence and DNRC gaging station

The Middle Fork of the Dearborn originates along the Continental Divide near Rogers Pass and drains approximately 68 square miles. The median elevation of the Middle Fork drainage is 4,982 ft. The Middle Fork gage is located approximately 100 yards above the confluence with the Dearborn River. Approximately 475 acres are irrigated above the Middle Fork gage.

The hydrograph of the Middle Fork of the Dearborn (Figure 11), though smaller in magnitude, is similar to the hydrographs of the mainstem of the Dearborn River. Variability in pre-runoff flows and the timing and duration of peak flows in late May/early June mimic conditions found along the Dearborn River. Peak flows were observed to quickly drop as the snowpack in the headwaters was depleted. One difference of note is the lack of a defined runoff peak in 2007. A defined peak was present in all the hydrographs of the mainstem of the Dearborn in 2007.

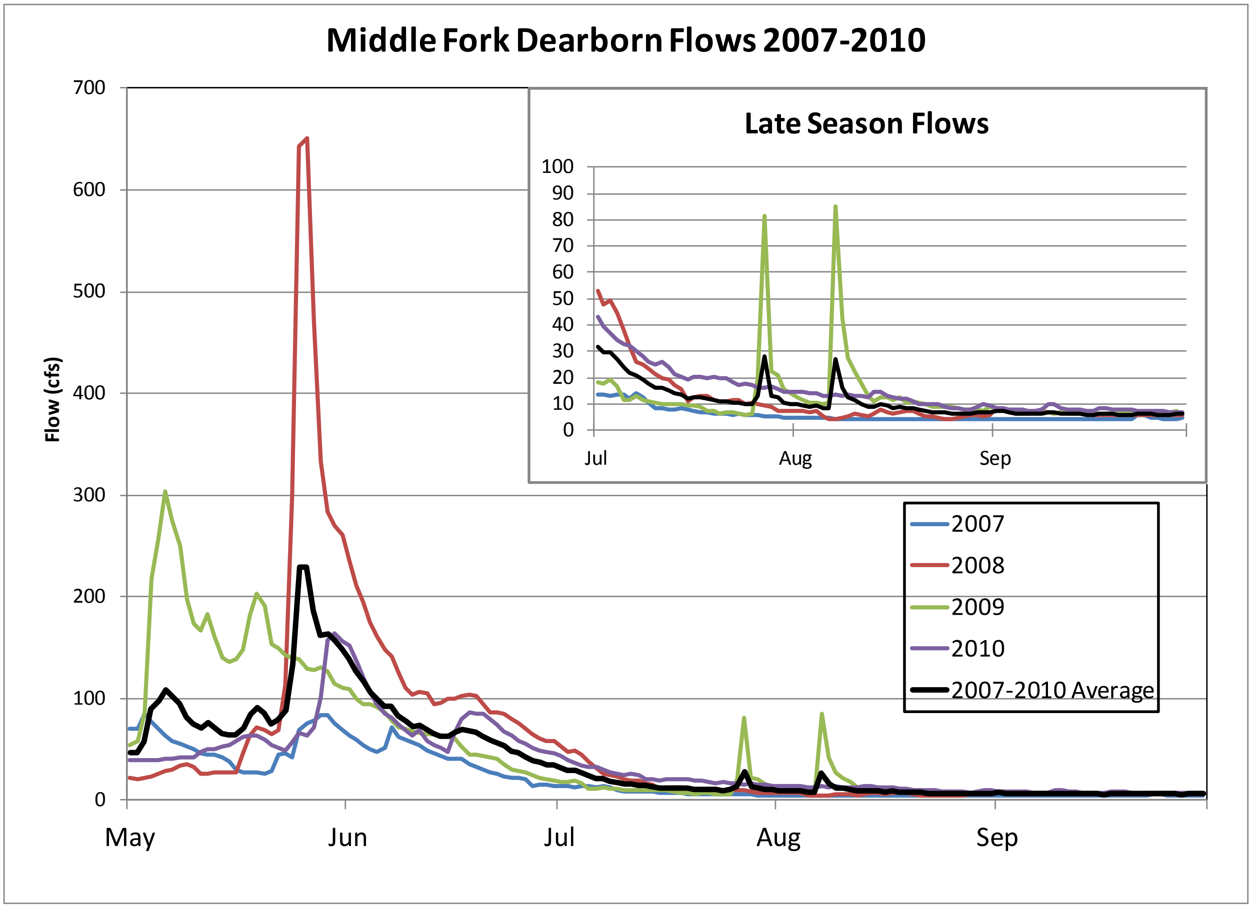

Figure 11: Hydrograph of the Middle Fork of the Dearborn River 2007-2010.

During the study the highest daily average peak flow of 650 cfs was estimated on May 26th 2008. The lowest daily average peak flow of 84 cfs was recorded on May 29, 2007. The average of daily peak flows is 300 cfs. Peak flows (>160 cfs) shown in the graph are an estimate and exceeds the limits of the rating curve for this station.

Low flow conditions on the Middle Fork were observed to start in mid-July. Late season flows (August-September) averaged 8 cfs over the study period. Surface water flows tended to decrease into September when the lowest discharges over the measuring season are observed. The lowest discharge recorded at the Middle Fork was 4 cfs on August 22, 2007. The timing of the lowest flow measurement is approximately 26 days earlier than the Upper Dearborn site.

In late July and early August of 2009, convective storms added significant flow to the Middle Fork but the increases were temporary as flow pulses quickly moved through the system.

The highest flow volumes were observed in May and June during the study (Figure 12). Flow volumes dropped dramatically in July coinciding with the end of runoff and the beginning of summertime low flows. The volume of water passing through the Middle Fork site during runoff (May through July) averaged 12,500 af during the study with a high of 16,700 af in 2008 and a low of 6,800 af in 2007.

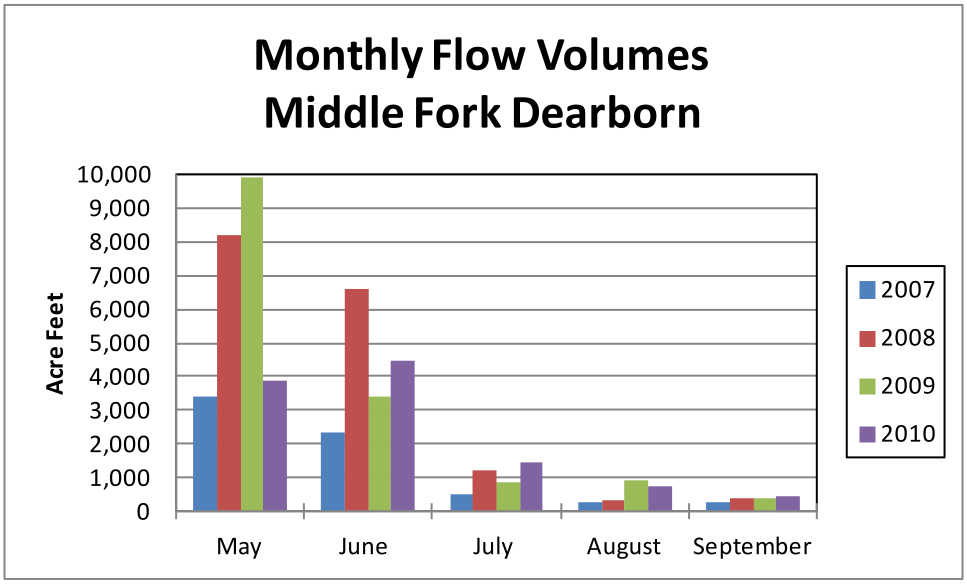

Figure 12: Monthly flow volumes at the Middle Fork Dearborn site.

South Fork Dearborn

South Fork of the Dearborn River below Highway 434 and DRNC gaging station

The South Fork of the Dearborn originates along the Continental Divide directly south of the Middle Fork drainage. The South Fork drains approximately 46 square miles. The median elevation of the South Fork drainage is 4,931 ft. The South Fork gage is located at the Highway 434 crossing which is approximately 3 miles above the confluence with the Dearborn. The South Fork gage is located below the majority of irrigation withdrawals in the drainage. Irrigation withdrawals above the gage service approximately 566 acres of irrigation. Gaging at this location is representative of the majority of depletions from the South Fork. However, depletions and return flows below the gage from irrigation are likely.

The South Fork hydrograph (Figure 13) is similar to conditions found on the Middle Fork.

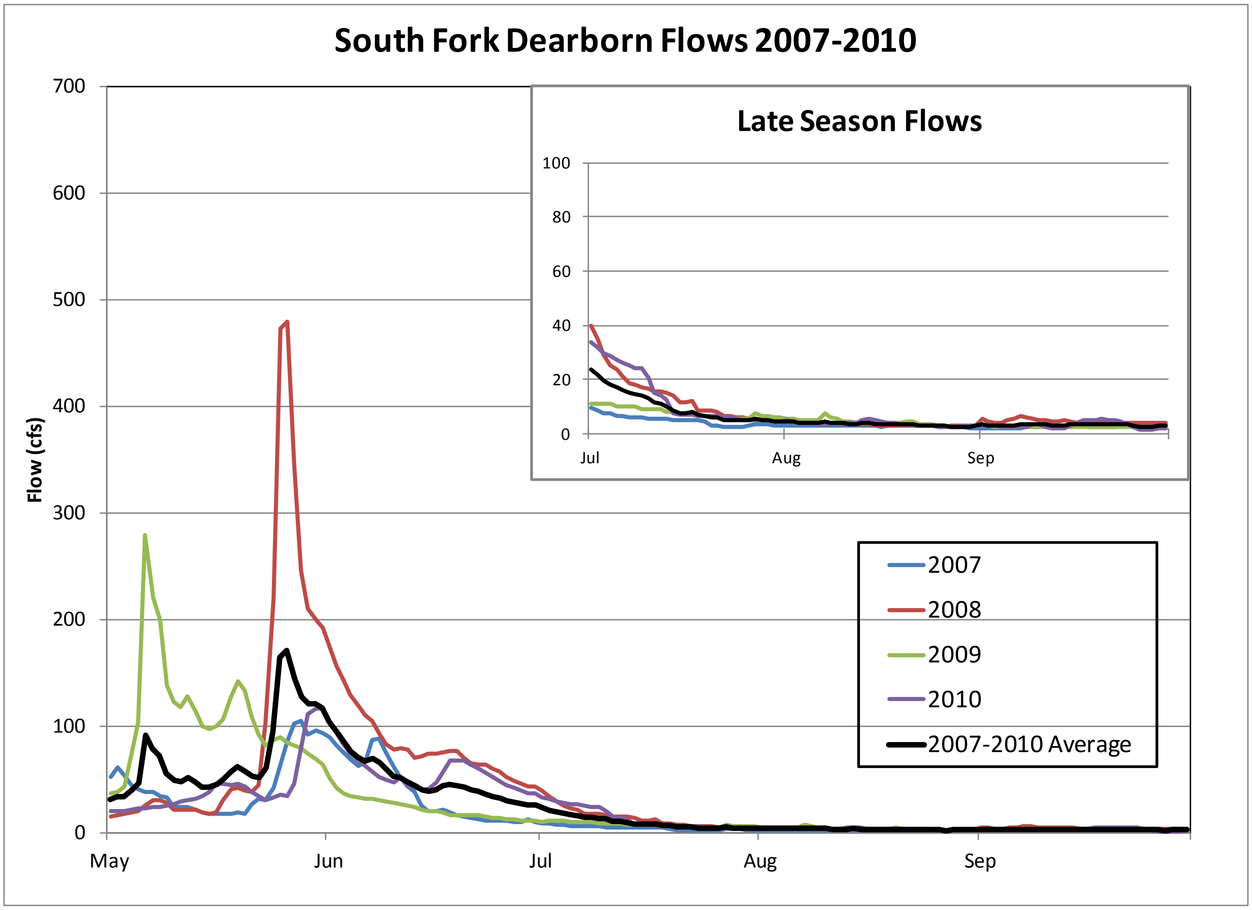

Figure 13: Hydrograph of the South Fork of the Dearborn River 2007-2010

Variability in pre-runoff flows and the timing and duration of peak flows in late May/early June mimics conditions found along the Dearborn River. Peak flows were observed to quickly drop as the snowpack in the headwaters was depleted. The South Fork hydrograph did contain a well-defined runoff peak in 2007 which is similar to conditions found on the mainstem of the Dearborn.

The highest daily average peak flow during the study period of 480 cfs was recorded on May 26, 2008. The lowest daily peak average flow of 105 cfs was recorded on May 28, 2007. The average of daily peak flows is 245 cfs. Peak flows (> 450 cfs) shown in the graph are an estimate and exceeds the limits of the rating curve for this station.

Low flow conditions on the South Fork were observed to start in mid-July. During the study period, late season flows (August-September) averaged 3.5 cfs. Surface water flows tended to decrease into the month of September at which time the lowest discharges over the measuring season are observed. The lowest discharge measured at the South Fork site was 2.1 cfs September 3, 2007.

Effects of irrigation depletions and return flows cannot be computed on the South Fork of the Dearborn through gaging data because the gage at the Highway 434 crossing was below the majority of irrigated lands/diversions. It is assumed that flows measured at the South Fork gage are representative of irrigation depletions to the South Fork and representative of flow contributions of the South Fork to the mainstem of the Dearborn River.

Unlike the Middle Fork, convective storms did not add any significant flows to the South Fork during the study period. Late season flow increases were observed in 2008 and 2010. These flow increases are related to fall precipitation events in the drainage.

Monthly flow volumes at the South Fork site are presented in Figure 14. The highest flow volumes were observed in May and June during the study. Flow volumes dropped dramatically in July coinciding with the end of runoff and beginning the period of summertime low flows. The volume of water passing through the South Fork site during runoff (May through July) averaged 8,500 af during the study with a high of 12,300 af in 2008 and a low of 5,700 af in 2007.

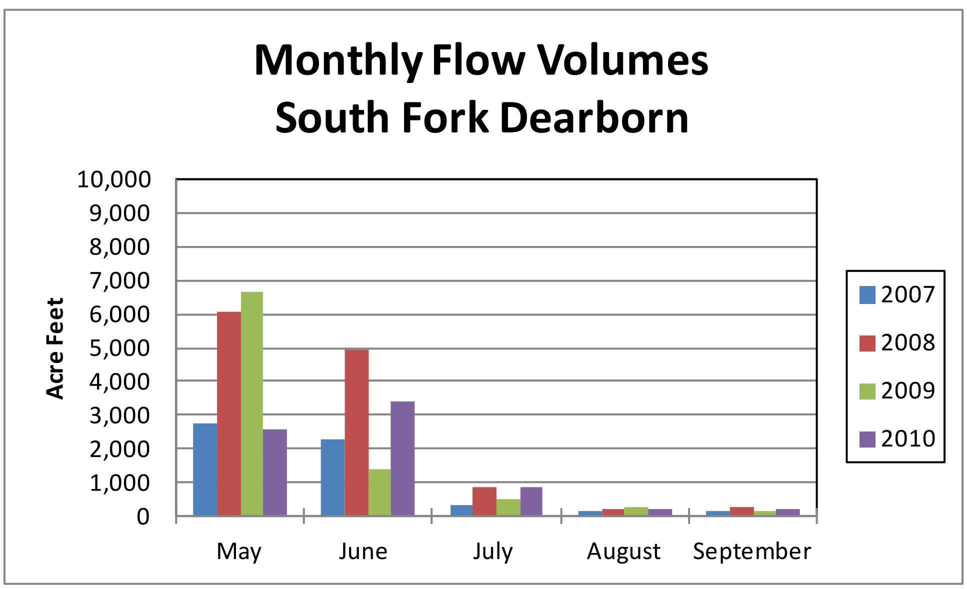

Figure 14: Monthly flow volumes at the South Fork Dearborn site.

Flat Creek Estimated Natural Flow

Flat Creek originates east of the Continental Divide in the lower elevation foothills. Flat Creek has the largest drainage area of any tributary at 135 square miles and accounts for 25% of the land area of the Dearborn drainage. The median elevation of the Flat Creek drainage is 4,300 ft. Dearborn River water is diverted via the Dearborn Canal into the headwaters the Flat Creek drainage to irrigate lands in the Flat Creek valley.

The hydrograph of Flat Creek is considerably altered by the addition of Dearborn River water. The natural hydrograph and inflows to Flat Creek (above the Dearborn Canal) were not measured. A regression equation was developed to estimate natural flows in the Flat Creek drainage, without the introduction of Dearborn River water, based on watershed characteristics for the other Dearborn basin streams that were gaged during the study.

$$Y = b + m1x1 + m2x2$$

Y= Seasonal Discharge (Acre-Feet)
X1= Regression Coefficient
X2= Regression Coefficient
M1=Median elevation/10 (Feet)
M2= Area (Square miles)
b= intercept

The regression equation used seasonal flow volumes (May 1 to Sept 30th) in acre feet for gaged locations in the watershed as dependent variable. The median drainage elevation (divided by 10) and drainage area of the gaged locations were used as independent variables. Division by 10 reduced the median drainage elevation to same order of magnitude as the other variables.

A unique regression equation was created for each year of the study. The R squared values ranged from 0.98 to 0.99. Monthly flow volumes were computed from the estimated seasonal total by calculating the monthly percentage of flow volume that passed the USGS gage 6073500, Dearborn River near Craig from May 1st to September 30th for each year. The calculated percentage was then applied to the estimated natural seasonal flow of Flat Creek.

Estimated monthly natural flows for Flat Creek drainage are presented in Table 2 as well as the measured flows at the lowest gage on Flat Creek at the Flat Creek Canyon Gage, which reflect natural inflow, flows added by the Dearborn Canal and irrigation depletions.

Estimated Flat Creek Drainage Natural Flow in Acre Feet (May 1 - Sept 30th)						
	May	Jun	Jul	Aug	Sep	Total
2007	872	624	153	59	51	1,759
2008	2,077	1,548	457	111	149	4,343
2009	2,290	1,137	322	296	134	4,178
2010	821	1,265	364	156	116	2,722
Average	1,515	1,143	324	156	113	3,251
F.C Canyon Gaged Average	2,661	1,845	1,325	813	852	7,496

Table 2: Estimated monthly flow in Acre-Feet for Flat Creek.

Flat Creek Highway 200 Gage

Flat Creek at highway 200 and DNRC gaging station

The Flat Creek gage at Highway 200 is located approximately 14 miles downstream of where diverted Dearborn River water first enters the Flat Creek drainage and is representative of conditions found in the middle reach of the creek. Approximately 3,277 acres of irrigated land exist above the gage in the Flat Creek drainage.

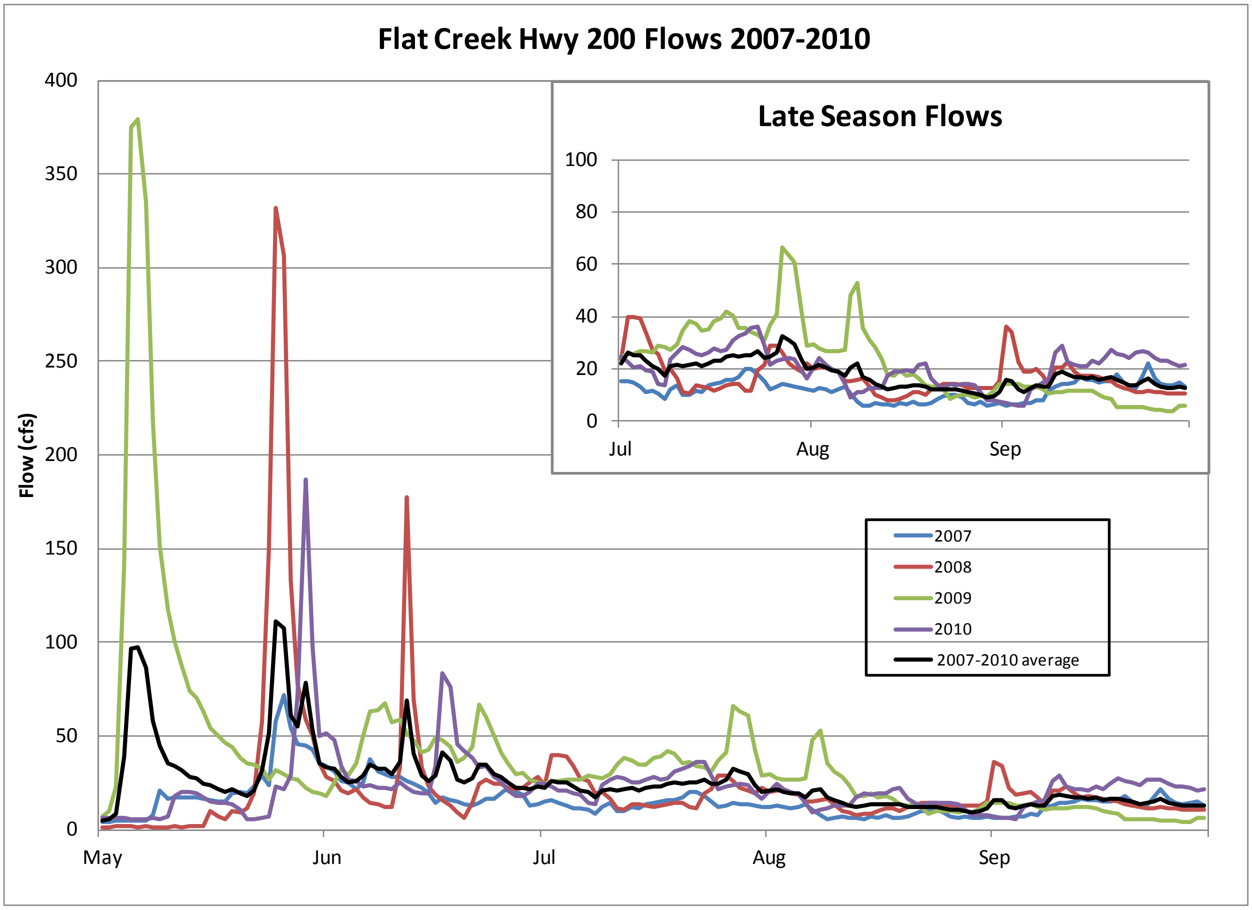

Figure 15: Hydrograph of the Flat Creek Highway 200 site 2007-2010.

The hydrographs of the Flat Creek gages (figures 15 & 17) are significantly different than the other sites due to the flow alterations caused by the diversion of Dearborn River water. High flow spikes are evident in May and June. These spikes are very short in duration and are the result of precipitation or the melting of low elevation snow in the Flat Creek watershed. The remainder of the hydrograph is dominated by contributions to Flat Creek by the Dearborn Canal Company diversion.

In addition to snowmelt/precipitation, higher flows are observed in late May and June as more water is available for diversion from the Dearborn River. During the study period, the highest daily average peak flow of 379 cfs was recorded on May 6, 2009. The lowest daily peak average flow of 72 cfs was recorded on May 26, 2007. The average of daily peak flows is 240 cfs.

Flat Creek is sustained from July to September with fluctuating flows in response to irrigation demands that depend on cutting/haying periods and /or weather. Spikes in the hydrograph observed in August 2008 and September 2009 are related to natural runoff generated from precipitation events. Flows were observed to increase in early to mid-September as irrigation demands decrease. Flows decline from mid to late September when the Dearborn Canal shuts down for the winter months. Variability during the study period is also evident at this gage as changes in water supply affect flows diverted to Flat Creek.

The lowest flow conditions measured at the Flat Creek Highway 200 site occurs in early May prior to the start of Dearborn River diversions. The lowest flow observed, 1.5 cfs, occurred on on May 1, 2008.   During the irrigation season the lowest flows begin in mid-August with the lowest irrigation season discharge of 6 cfs on August 10, 2007. Late season flows (August-September) averaged 14.6 cfs over the study period.

The highest monthly flow volumes at the Flat Creek Highway 200 site were observed in May (Figure 16). Flow volumes dropped consecutively each month from May to September as water diversions from the Dearborn River decreased. The volume of water passing through the Flat Creek Highway 200 site during the irrigation season (May through September) averaged 7,775 af during the study with a high of 11,966 af in 2008 and a low of 4,819 af in 2007.

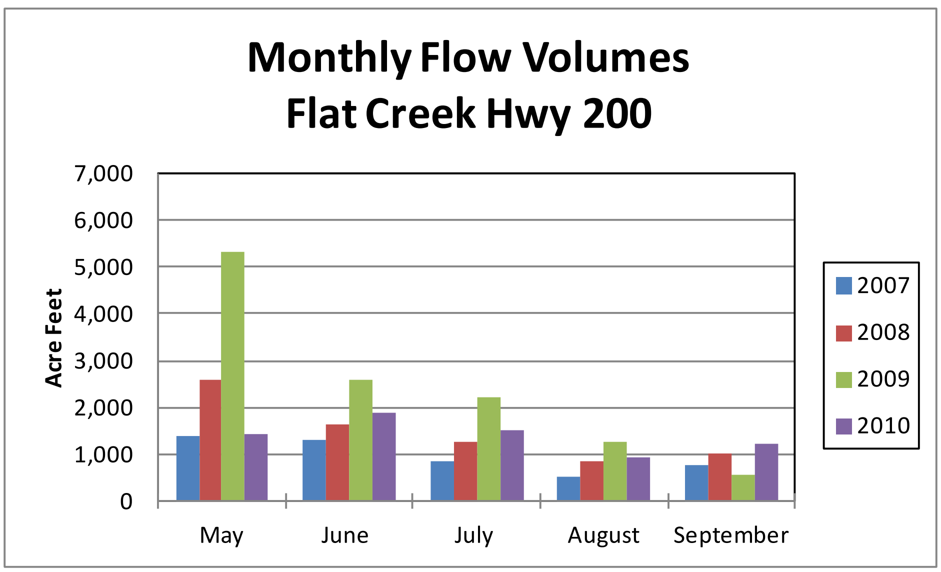

Figure 16: Monthly flow volumes at the Flat Creek Highway 200 site.

Flat Creek Canyon Gage

Flat Creek at the Canyon site and DRNC gaging station

The Flat Creek Canyon gage is located approximately eight miles downstream of the Highway 200 gage and is representative of conditions found in the lower reaches of the creek. This site is located below all of the approximately 4,045 irrigated acres in the Flat Creek drainage Figure 2). Flat Creek changes below the gage dramatically as the floodplain and creek are constricted by the volcanic rocks of the Adel formation.

The Flat Creek Canyon hydrograph (Figure 17) is more stable after July 1st when compared to the hydrograph at the upstream gage located at Highway 200. The location of the gage (Canyon site) likely influences the flow stability, as flows passing by the gage are a combination of unused water diverted by the Dearborn Canal, irrigation return flows, natural flows and groundwater contributions. During the study period the highest daily average peak flow of 397 cfs was recorded on May 6, 2009. The lowest daily peak average flow of 29 cfs was recorded on May 26, 2007. The average of daily peak flows is 231 cfs.

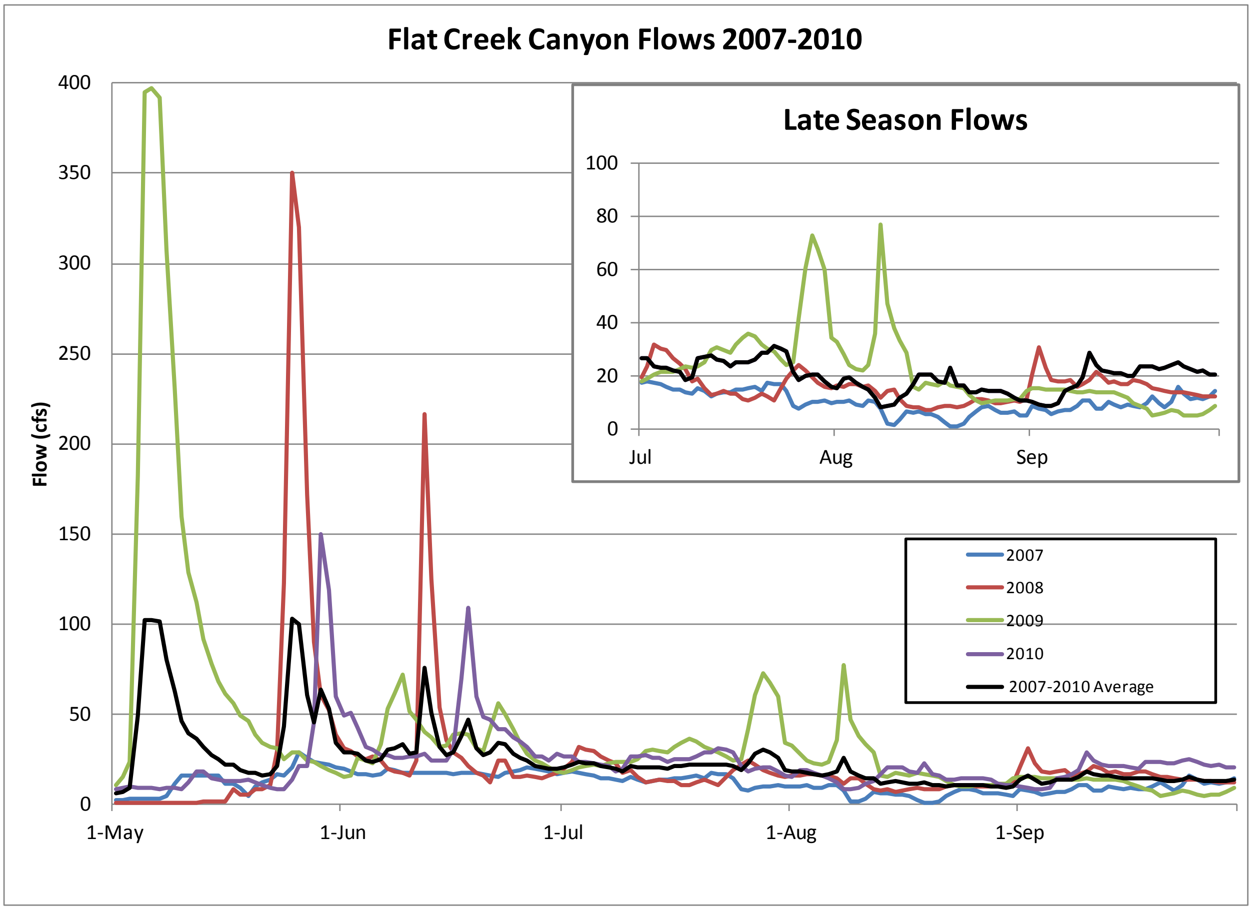

Figure 17: Hydrograph of the Flat Creek Canyon site.

The lowest flow conditions were observed at the Flat Creek Canyon site in early May prior to the start of the Dearborn Canal diversions. The lowest flow observed, 1.1 cfs, was observed on May 1, 2008.   During the irrigation season the lowest flows were observed to start in mid-August. The lowest irrigation season discharge measured at the Flat Creek Canyon site was 1.2 cfs on August 20, 2007. During the study period late season flows (August-September) averaged 14 cfs.

The highest flow volumes at the Flat Creek Canyon site were observed in May and June during the study (Figure 18). Flow volumes dropped consecutively from July to September as water supply conditions decreased on the Dearborn River. The volume of water passing through the

Flat Creek Canyon site during the irrigation season (May through September) averaged 7,654 af during the study with a high of 12,328 af in 2008 and a low of 3,701 af in 2007.

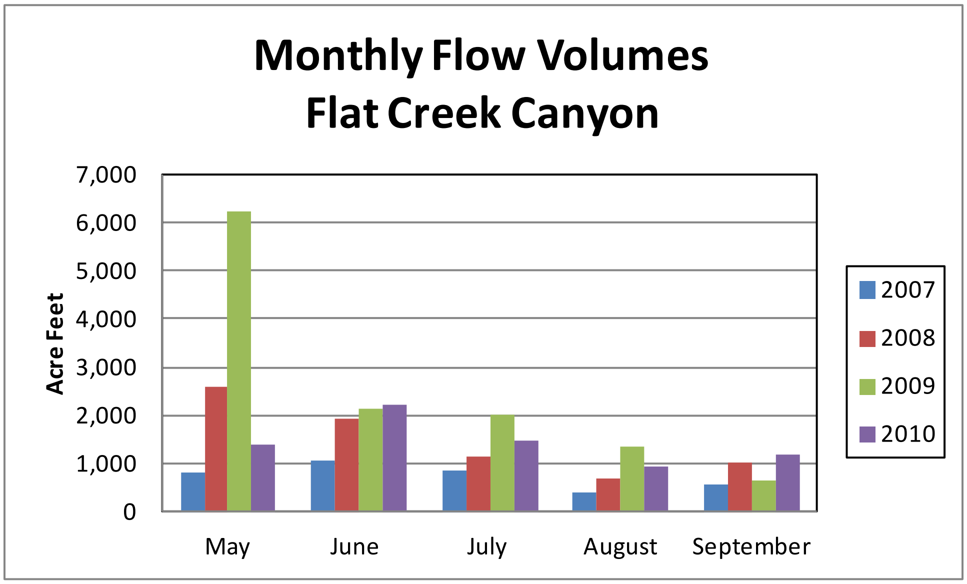

Figure 18: Monthly flow volumes at the Flat Creek Canyon site.

Flow Contributions of the Upper Dearborn River and Tributaries

The average gaged inflow volumes over the study period were summed for the Upper Dearborn, South Fork and Middle Fork gages from May through September. To this, estimated natural flows for Flat Creek, calculated using regression equations, were added. The total estimated average inflow volume was 95,500 af. The Upper Dearborn (headwaters inflows) accounts for 75% of the inflow to the basin (Figure 19). The South Fork and Middle Fork account for 9 and 13 % of the inflows respectively. The estimated natural flows of Flat Creek contribute approximately 2,400 af or 3% of the annual inflow volume.

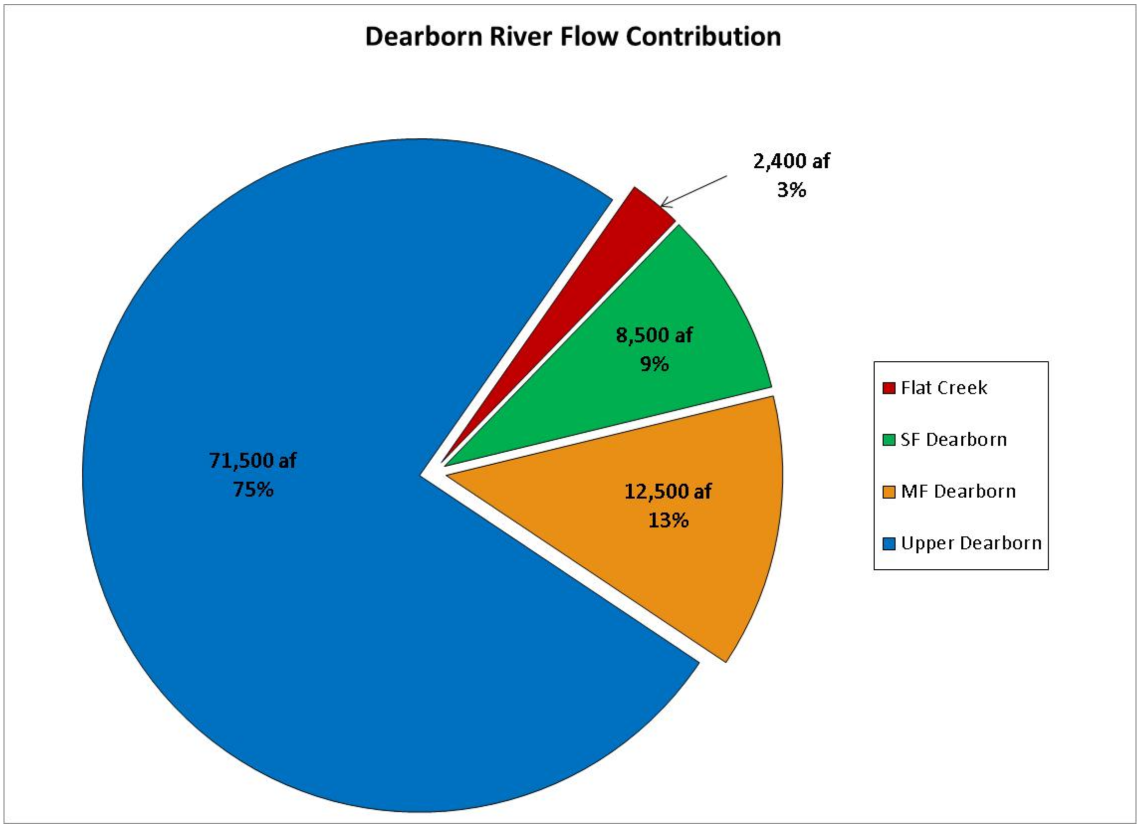

Figure 19: Pie chart of Dearborn River inflows by average total yield and percent of total.

Stream Flow and Water Supply Conditions during the Study

Precipitation

The National Resource Conservation Service (NRCS) maintains a SNOTEL (Snowpack Telemetry) station at Wood Creek located in the Sun River drainage, approximately 23 miles north of the Upper Dearborn station and 12 miles from the headwaters of the Dearborn drainage. The Wood Creek SNOTEL site (Station ID 876), at an elevation of 5,960 ft, has operated since October 1978. The Wood Creek station data provides information about the amount of precipitation received in the headwaters of the Dearborn watershed over the study period relative to the long term and is useful in interpreting steam flows. The Wood Creek station is representative of mid-elevation snowpack. Approximately 25 % of the Dearborn basin's land mass is located at or above the elevation of the Wood Creek SNOTEL.

Precipitation data over the study period is compared to the 30 year "Normals" (1981-2010) using the 30 year average for accumulated precipitation and the 30 year median for Snow Water Equivalent (SWE). The cumulative snowpack and precipitation (Figure 20) data are plotted for the 2007-2010 water years for comparison.

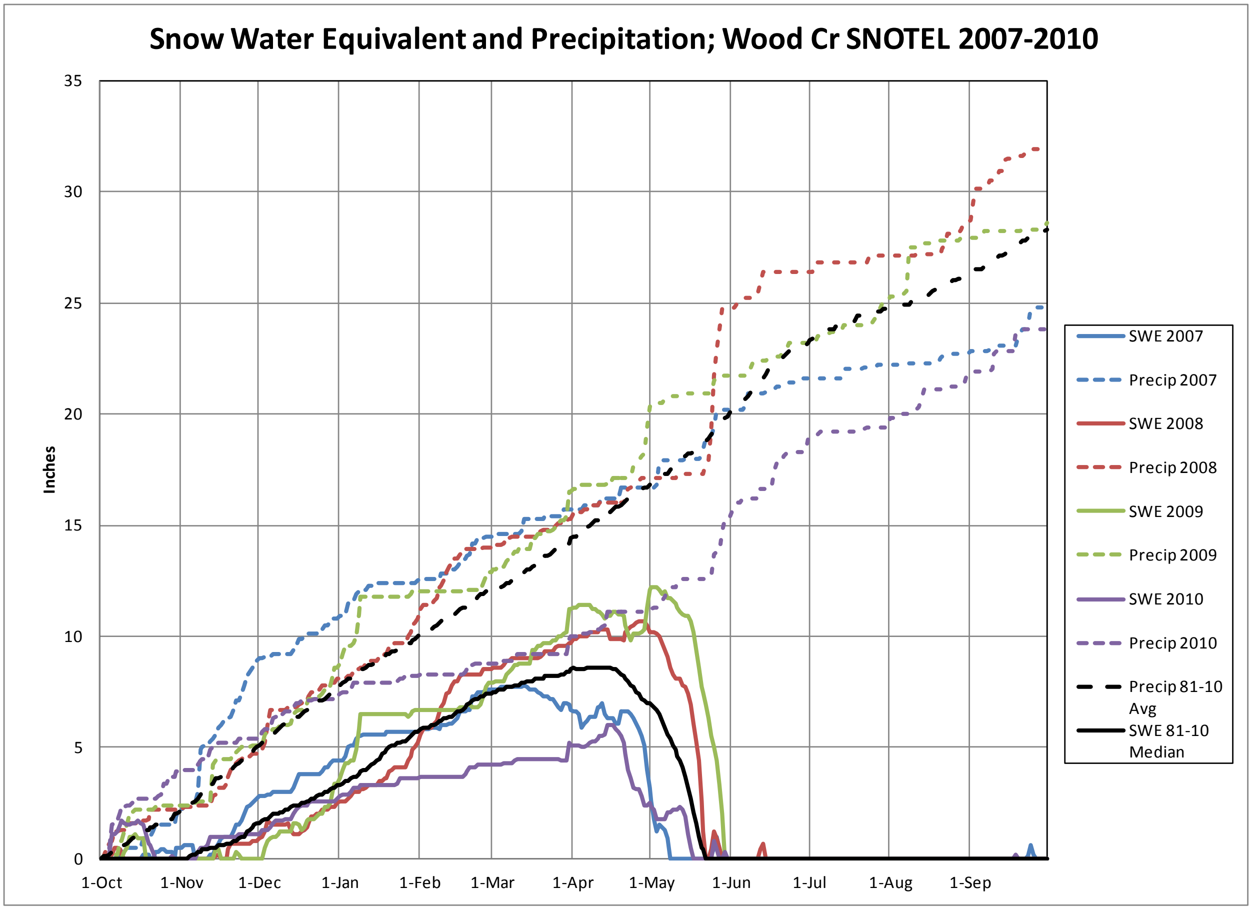

Figure 20: NRCS SNOWTEL data Wood Creek Station 2007-2010.

Presenting both SWE and precipitation data give insight into how precipitation in the headwaters can affect streamflows in the watershed. Snow accumulation provides the primary water source for the Dearborn River. In addition, early spring and fall rains can add significantly to flows and can even cause flooding.

The SWE indicates that the snowpack was above the thirty year normal for the winters of 2008 and 2009, and below normal in 2007 and 2010. The highest snowpack for the four year period was 2009 and the lowest 2010.

Figure 19 depicts the timing of peak snowpack accumulation and the melting of the snowpack. The normal peak snowpack occurs in mid-April and the snowpack is normally depleted by the last week in May. The highest elevations of the watershed are over 3,000 feet higher than the Wood Creek SNOTEL site and peak snowpack accumulation is generally higher and timing of melt usually later as elevation increases.

In 2008 and 2009 the snowpack continued to accumulate in late April – early May and melt later than normal. Conversely, the snowpack stopped accumulating in March and began to melt earlier than normal in 2007. The accumulation of the snowpack in 2010 was less than normal however, the timing of snowmelt was normal.

Precipitation, including both snow and rain, was below normal in 2007 and 2010, near normal in 2009 and above normal in 2008.

Streamflow

The study was designed to collect data over a four year period with the intent of measuring flows over varying hydrologic and climatic conditions. A comparison of flow conditions over the 4-year study period to long-term records provides a better understanding of how the observed hydrologic conditions compare historically.

The USGS gage above the Highway 287 Bridge is the only long term monitoring site in the study area with about 44 years of steam flow records. Mean daily flows for 2007-2010 were compared to the historic record from the USGS site (1946-present) (Figure 21). The hydrograph indicates that flows on the Dearborn River typically begin to rise from winter base flow conditions in mid-March as low elevation snow begins to melt. Flows continue to rise over the spring until the river peaks in late May through early June, with high flows typically sustaining through late June. High flows subside to summer low flows by mid-July, low flow summer conditions transition to fall and winter base flow conditions.

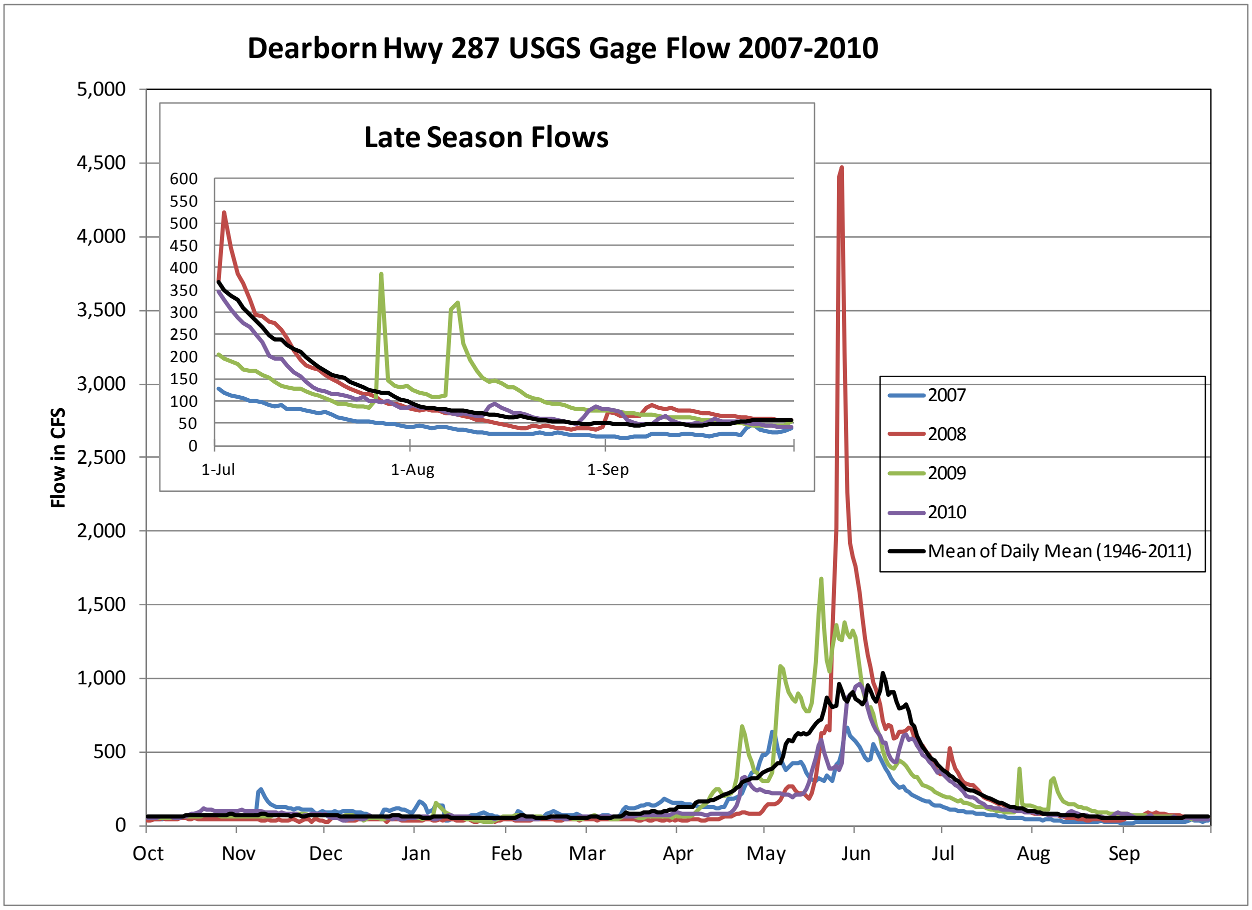

Figure 21: Daily Average Flows USGS gage 6073500 at Dearborn Highway 287 bridge.

During the study period (2007-2010) the timing of peak flows was generally slightly earlier than normal. Instantaneous peak flows ranged from 707 cfs to a 5,150 cfs. The historical average instantaneous peak flow is 2,600 cfs. The maximum peak flow of 15,400 cfs was recorded 1964. Historical mean of daily mean peak flows tend to be flattened as the timing of peak flows varies from year to year.

Late season flows over the study period were near average with the exception of 2007 which remained below average during the entire late summer and fall. The late season hydrograph of water years 2008, 2009 and 2010, indicates that flows rose above and fell below the 44 year average as summer rains added flow and depletions from the system reduced flows. The dynamic nature of the system is evident when looking at flows on a daily time step.

High flow events are generally a result of rain-on-snow events that forces rapid snowmelt in the late spring. A rain-on-snow event on May 26, 2008 created a flood event that was measured to a crest of 5,150 cfs at the USGS gage indicating the event was the fifth largest peak flow to be recorded to date.

Flow data at the USGS gage over the study period is presented in monthly time steps in Table 3. Statistical data, including the monthly average and median, was calculated over the study period. Historical long term flow data are also presented as monthly average, median and lower quartile (Q_{25}) and upper quartile (Q_{75}). The lower and upper quartile flows represent lowest and highest 25 percent of flows over the period of record and provide good reference points to characterize high and low flow conditions.

The table indicates the dynamic nature of the Dearborn River system as three out of the four study years have both dry and wetter conditions during the same year: monthly average flows below the lower quartile and monthly average flow above the long term average.

Overall, flows during the study were most often near average to the drier side of the average; flows were below the lower quartile a similar amount of time as they were above the average.

	Average Monthly Flow in CFS at USGS Gage 6073500													
Water Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**May -Sept Volume (acre-feet)**	**Water Year Total (acre-feet)**
2007	44	38	40	83	70	111	200	438	313	77	30	26	52,503	96,944
2008	60	69	57	36	40	40	61	961	716	212	51	69	119,536	139,587
2009	78	85	51	56	57	59	248	1007	500	141	130	59	109,343	148,203
2010	42	37	37	56	49	68	138	380	586	169	72	54	74,988	107,804
Average	56	57	46	58	54	69	162	696	529	150	71	52	89,092	123,134
Median	52	54	46	56	53	63	169	699	543	155	62	56	90,157	123,695
	Long Term Records (1945-2011)													
Average	69	71	63	55	58	81	225	689	741	199	66	55	100,847	141,206
Median (Q_{50})	63	63	57	51	52	73	184	650	570	151	58	45	85,037	139,587
Lower Quartile (Q_{25})	46	47	44	41	42	52	120	422	360	100	41	31	54,933	99,658
Upper Quartile (Q_{75})	81	93	80	63	65	106	327	958	894	282	84	57	131,965	169,814

Table 3: Monthly flow statistics for Dearborn River at USGS Gage 6073500: study period years compared to long-term records. Flows during the study above the long term average are highlighted in **Blue**. Flows below the lower quartile are highlighted in **Orange**. Average to lower quartile flows are not highlighted.

Annual Water Supply

Annual flow volumes at the USGS Dearborn River at Highway 287 Bridge gage (6073500) are graphed in Figure 22 for the entire period of record. The average annual volume of 141,200 af is indicated with a black line. From an annual volume standpoint, 2008-2009 were near average while 2007 and 2010 were substantially below average. Six out of the ten lowest flow volume years occurred since the year 2000, with 2000 being the lowest flow volume on record.

The annual volume for 2007 was also below the lower quartile indicating that conditions observed in 2007 are representative of the lowest 25% of flows recorded in the 44 years of gaging.

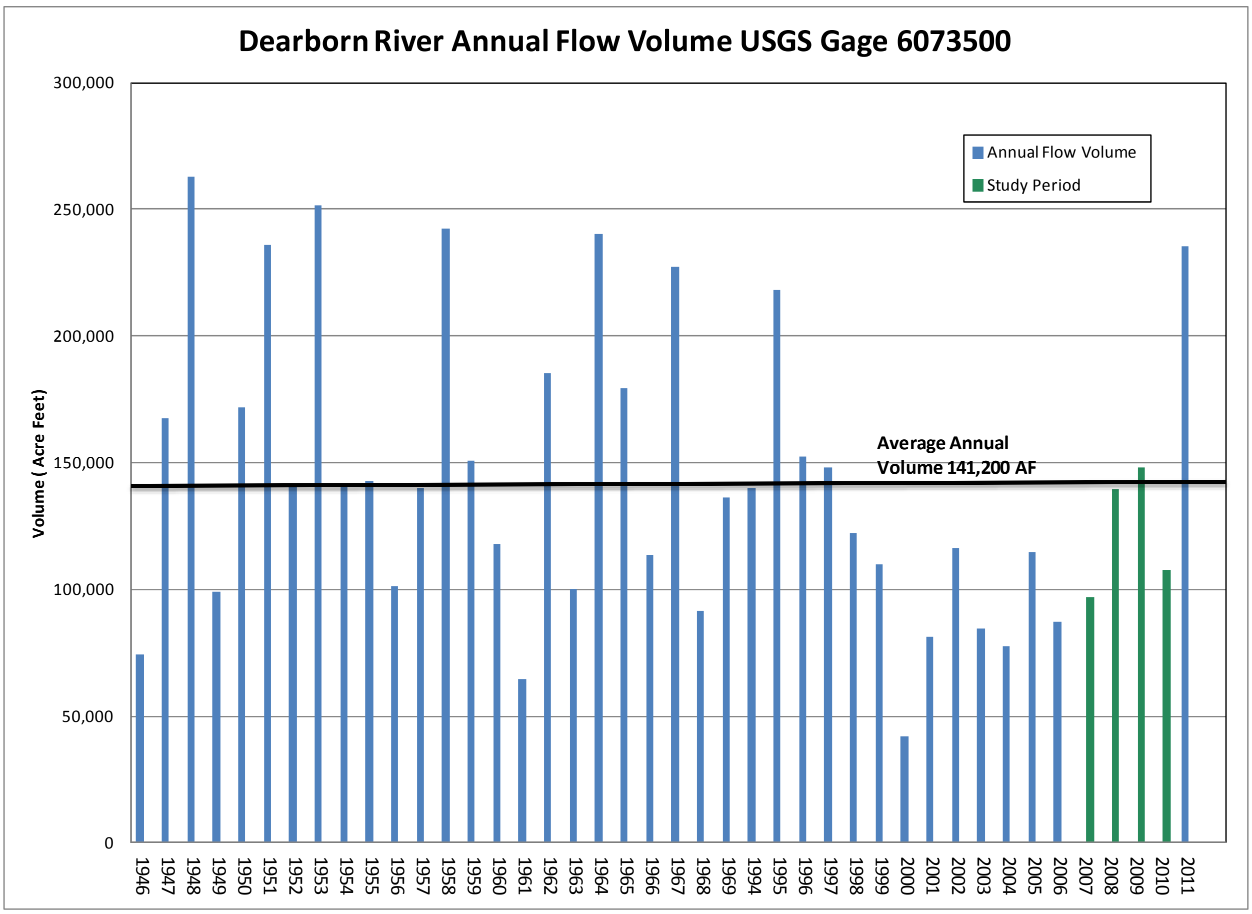

Figure 22: Annual flow volume in acre-feet for USGS gage 6073500 Dearborn River near Craig, MT.

The annual flow volume graph indicates historic variability in annual flow volumes. Since gaging was reinstated in 1994 flow volumes have been below average more frequently.

Synoptic Flow Measurements and System Gains and Losses

Synoptic flow measurements provide a snapshot of flow conditions by gathering discrete discharge measurement at representative locations in the system. Using the synoptic measurements, gains and losses within a particular reach can be computed by adding or subtracting upstream flows and tributary inflow. Synoptic measurements were taken after runoff, in the summer and during the early fall, when flow conditions were relatively stable. USGS gaging data from the Highway 287 Bridge was also used in the computations.

Synoptic flow measurements are presented in Table 4. Flows could not always be measured at the Flat Creek Canyon site due to weather and time constraints. In these instances, flows from the Flat Canyon Highway site were used to estimate Flat Creek flow contributions.

Synoptic Flow Measurements								
	Upper Dearborn	**Middle Fork**	**Dearborn Hwy 200**	**Flat Cr Hwy 200**	**South Fork**	**USGS Hwy 287**	**Flat Cr Canyon**	**Dearborn Mouth**
Date	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
7/10/2007	98	11.1	85.3	15.5	8.25	89	Not Measured	111
8/15/2007	54.7	4.72	27.6	5.88	2.35	25	Not Measured	37.4
9/11/2007	42	2.88	21.6	13.5	2.47	23	7.61	35.3
8/26/2008	63.8	4.64	35.05	12.63	2.63	35	10.91	49.8
9/23/2008	63.9	5.67	66.2	13.3	4.16	62	14.8	89.4
8/19/2009	107.5	11.6	118.2	12.6	5.1	113	Not Measured	143.8
7/7/2010	182.8	35.3	221.3	13.1	18.5	251	23.5	327.8
8/5/2010	93.5	12.5	90	19.2	3.6	80	14.9	113.4
9/15/2010	57.6	8.1	49.3	24.3	2.5	52	Not Measured	98.4

Table 4: Synoptic flow measurements made on the Dearborn River and tributaries during the study.

Gains and losses along the mainstem of the Dearborn River and Flat Creek are shown in Table 5. Tributary inflows were subtracted to examine gains and losses along the mainstem. The Dearborn River from the Upper Dearborn site to Highway 200 lost water during eight of the nine synoptic measurements. The loss ranges from 1 to 33 cfs with an average loss of 17 cfs. Inflows from the Middle Fork of the Dearborn were subtracted from the Highway 200 measurement to compute flow gains or losses in this reach of the mainstem. The addition of flows from Cuniff Creek, a relatively small tributary, was not separated out for in this estimate; however inflows attributed to Cuniff are expected to be minor. Measurement data suggest that losses in the stretch are due to the diversion of Dearborn River water to the Flat Creek drainage via the Dearborn Canal.

The Dearborn River from Highway 200 to Highway 287 lost minor amounts of water in seven out of nine measurements. The losses in this stream reach range from 1 to 14 cfs with an average loss of 6.5 cfs. Flow contributions from the South Fork are subtracted to compute gains and losses. The Dearborn River receives flow contributions from Auchard Creek in this stretch. However, flow contributions to the river by Auchard Creek were not observed during synoptic measurements. The majority of the losses observed in this stretch of the river are within the threshold of measurement error (+/- 5%), but likely there is frequently a loss in this reach with it occurring in 7 out of 9 measurements. Irrigation withdrawals are present in this reach of the river and are likely contributing to the losses. The data indicate a trend of water loss in the Highway 200 to 287 reach.

The Dearborn River from Highway 287 to the Dearborn Mouth site gained moderate amounts of water. The gain in flows ranged from 4 to 53 cfs with an average gain of 16 cfs. Flow contributions from Flat Creek were subtracted to examine gains and losses in this reach. In July of 2010, the greatest gain of water (53 cfs) was observed. The July 2010 synoptic run occurred during the highest flow conditions of all synoptic runs. These gains in July 2010 are likely the result of surface runoff conditions still present in the ephemeral and ungaged tributaries, and contributions from Flat Creek below the Canyon site. Groundwater may play a role in gains along this section; however with limited measurements the interaction of groundwater cannot be quantified.

The reach between Flat Creek Highway 200 and Flat Creek Canyon indicated a loss on three out of four measurements. The losses in this reach likely resulted from irrigation diversions.

Reach Gains and Losses				
	Upper Dearborn to Hwy 200 (minus Middle Fork)	**Dearborn Hwy 200 to Hwy 287 (minus South Fork)**	**Dearborn Hwy 287 to Mouth (Minus Flat Cr)**	**Flat Cr Hwy 200 - Flat Cr Canyon**
Date	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
7/10/2007	-24	-5	7	NA
8/15/2007	-32	-5	7	NA
9/11/2007	-23	-1	5	-6
8/26/2008	-33	-3	4	-2
9/23/2008	-3	-8	13	NA
8/19/2009	-1	-10	18	NA
7/7/2010	3	11	53	10
8/5/2010	-16	-14	19	-4
9/15/2010	-16	0	22	NA

Table 5: Calculated Gains and Losses Based on Synoptic Flow Measurements.

Table 5 shows the calculated reach gains and losses based on synoptic flow measurements made during the study. Note: negative values indicate a loss of water and positive values indicate a gain. NA indicates that a measurement was not taken at Flat Creek Canyon on that day.

Additional synoptic flow measurements were made on the Dearborn River in April and July of 2012. Measurements were made at the Dearborn Canyon Bridge located approximately 2 miles below the Dearborn Canal diversion, Highway 434 Bridge and Highway 200 Bridge above the Middle Fork (See Table 6). Flow measurements indicate that the gains in the Dearborn River between the Dearborn Canyon Bridge and Highway 200 above its confluence with Middle Fork are relatively small.

The 2012 measurements validate use of the Upper Dearborn and Middle Fork Dearborn and Dearborn at Highway 200 sites to estimate diversions into the Dearborn Canal under non-runoff conditions.

Site	April 17, 2012 Flow (cfs)	Change (cfs)	July 3, 2012 Flow (cfs)	Change (cfs)
Dearborn Canyon Bridge	84		119	
Hwy 434 Bridge	91	7	128	9
Hwy 200 Bridge (above Middle Fork confluence)	88	3	120	8

Table 6: Synoptic Flow on Upper Dearborn River 2012

Examination of groundwater interactions along the Dearborn River was not explicitly addressed during the study. Inferences can be made on how the Dearborn River interacts with groundwater. DNRC flow measurements made in 2012 when surface runoff likely was low indicate gains and losses from the Dearborn River to the groundwater from the Upper Canyon Bridge to Highway 200 were nominal.

The local geology, which is not conducive to the development of aquifers, is most likely responsible for the observed lack of groundwater/surface water interaction in this reach. The Dearborn River has incised its current course in bedrock as a result of diversion by Pinedale aged glaciation (Foley, 1980). The resulting incision most likely does not allow the Dearborn River to have significant amounts of unconsolidated sediments in the floodplain thus limiting the amount of possible storage for groundwater.

Groundwater interactions from Highway 200 to the mouth are more difficult to assess due to the complicating inflows of ephemeral tributaries, South Fork and Flat Creek and irrigation withdrawals. The Adel Mountain Formation below the Highway 287 Bridge severely limits the extent of the floodplain of the Dearborn River. Groundwater is most likely discharged to the Dearborn shortly after entering the Adel Formation. Gains from groundwater may be contributing, at least partially, to the observed gains between Highway 287 and the mouth.

Irrigation Water Use

Irrigation withdrawals and consumption have a major effect on the hydrology of the Dearborn watershed. Irrigation withdrawals and consumptive use were estimated at a watershed and sub-watershed scale, rather than quantifying diversions and depletions for the numerous individual users. The Dearborn Canal Company total diversions have been specifically estimated because it is by far the largest single diversion in the watershed and because of the marked effect it has on the flow of both the Dearborn River and Flat Creek.

Irrigated Acres

Flood irrigation for grass hay and alfalfa production is the dominant consumptive water use in the Dearborn watershed, but sprinkler irrigation also is found throughout. The purpose of identifying irrigated lands was to get a representative, recent estimate that could be used with other information to quantify the volume of water diverted and consumed during the study period. The WRS indicates that 3,417 acres were irrigated in 1957, with an additional 805 acres potentially irrigable under the current systems. Of these acres, the WRS indicated that 2,437 acres were irrigated from the Dearborn Canal Company with an additional 707 acres potentially irrigable under that system. In 2005, the Final Lands Unit (FLU) GIS data set inventoried 3,905 acres as irrigated in the Dearborn watershed.

DNRC irrigated lands mapping efforts identified 6,220 acres of irrigated lands in the watershed and 1,776 acres of sub-irrigated lands (meaning cropped lands in riparian areas that benefit from shallow groundwater) during the study. The irrigated lands dataset created by the DNRC is the most representative of irrigation due to the methodology used and the recent completion of the dataset. The increase in irrigated acreage over the WRS dataset is most likely a function of time as 56 years has passed since the WRS survey. The difference between the DNRC and FLU datasets is attributed to the purpose of the two datasets. The FLU dataset was created to assess taxation of lands and irrigated and particularly partially irrigated lands were likely underestimated. Irrigated pasture was not counted by the FLU survey.

Table 7 below shows the distribution of DNRC calculated irrigated acreage throughout the watershed by sub watershed. Some irrigated lands were checked for accuracy by visually ground truthing from publically accessible roads.

	DNRC Mapped Irrigated Acres				
Location	**Total**	**Flood**	**Center Pivot**	**Other Sprinkler**	**Sub-Irrigated**
South Fork Dearborn River	566	24	542		457
Middle Fork Dearborn River	475	300	170	5	89
Auchard Creek	753	753			102
Main Stem Dearborn	381	286	78	17	28
Flat Creek	4,045	3,103	836	106	1,100
Total	6,220	4,466	1,626	128	1,776

Table 7: DNRC Mapped irrigated acres in the Dearborn watershed by location and irrigation type.

Of the 6,220 acres irrigated land identified within the watershed, approximately 4,045 acres (65%) lies along Flat Creek (Figure 23). Irrigated lands within the South Fork and Middle Fork watersheds total 566 acres and 475 acres respectively. In addition, approximately 381 and 751 acres are irrigated along the mainstem Dearborn and Auchard Creek respectively. Flood irrigation is the primary method of irrigation in the watershed with 4,466 acres (71%) in flood production, 1,626 acres (26%) in center pivot production and 128 acres (2%) in other sprinkler production (wheel lines and handsets).

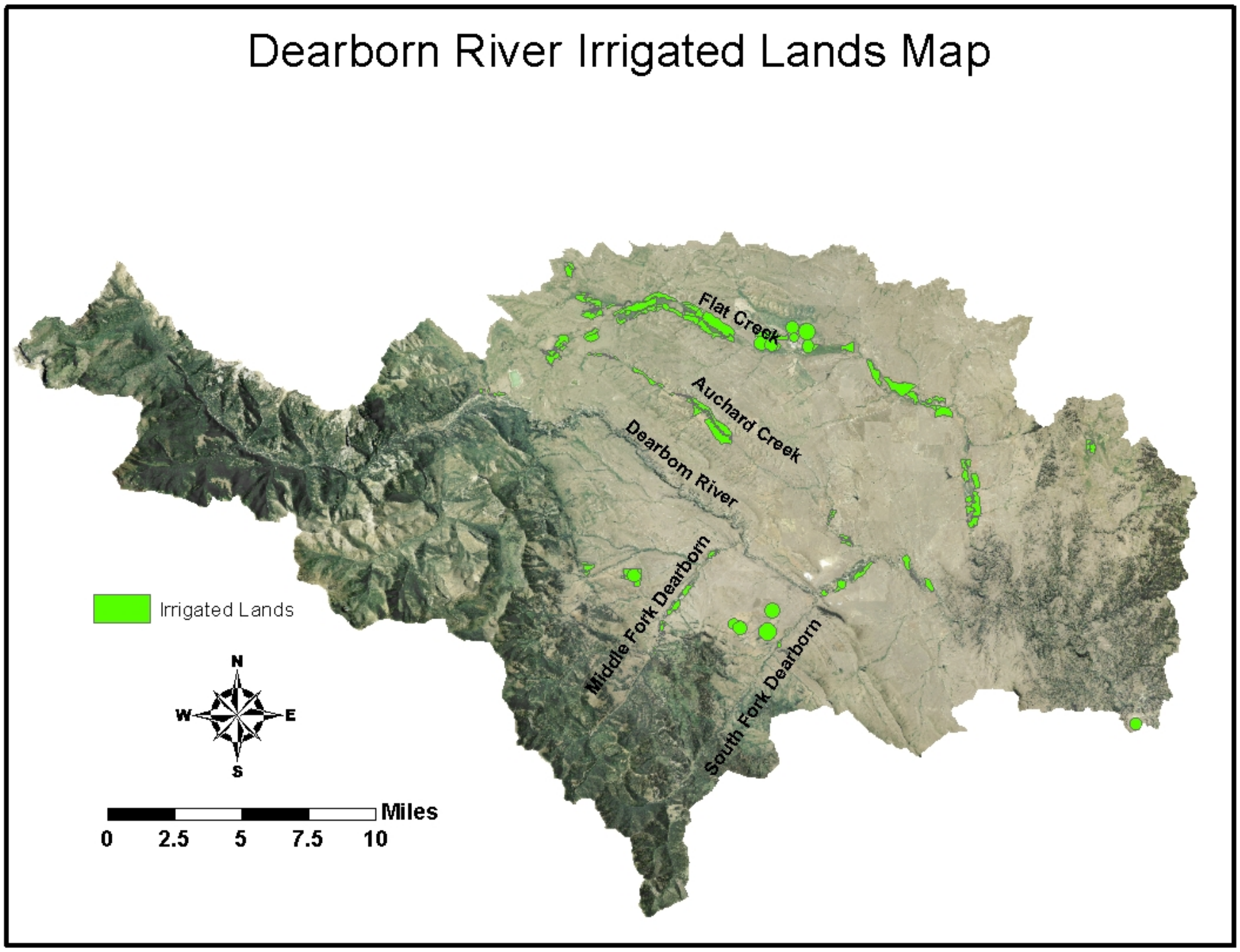

Figure 23: Irrigated lands identified by the DNRC.

Irrigation Season Hydrographs

The Dearborn Canal diverts Dearborn River water into Flat Creek. Once the diverted water enters the Flat Creek drainage, it is conveyed to fields via a series of ditches and by the creek. The Dearborn Canal was not directly measured because access to the canal was not granted. Average daily Dearborn Canal diversions were estimated using flow data from the Upper Dearborn, Dearborn Highway 200 and Middle Fork gages and the following equation:

Diversion = (Upper Dearborn Gage - (Dearborn Highway 200 – Middle Fork)).

Indirect measurement of the Dearborn Canal irrigation diversion is less accurate than direct measurement because three measurements are used, each of which introduces more potential for error. Indirect measurements are especially uncertain during high flow conditions in May and June, when the diversion rate is smaller relative to the total flow in the river. Ungaged inflows from smaller side tributaries between the two mainstem gages add another possible source of error. During periods of elevated flow, both negative and positive diversion rates were calculated, indicating the Dearborn River could have been gaining and losing water during these time periods at rates higher than the diverted amounts. Due to these issues, diversions estimates for the Dearborn Canal are only thought to be reliable for periods after runoff when flows in the Dearborn are less than approximately 400 cfs. Computed negative canal diversions were reported as zero for the purpose of this report.

The estimation of diverted volume is also sensitive to precipitation events that cause rising flow conditions. Precipitation from these events are generally not distributed in a uniform manner across the watershed, hence the streamflow response is not uniform. The non-uniform response at the three gaged locations caused the estimated diverted volumes to be negative.

Indirect daily mean measurements of the Dearborn Canal are discussed and presented graphically by each water year. Direct measurements of Flat Creek at Highway 200 and Canyon are presented to provide reference, because the Dearborn Canal diversions usually are providing most of the flow in Flat Creek during the irrigation season. Flow data from the Upper Dearborn gage is presented for the late season to depict how much is being diverted relative to the total flow in the river. Precipitation from the Rogers Pass is plotted on a secondary axis to provide reference of uncertainty.

The estimated diversion is plotted as a dashed red line during the spring, to indicate uncertainty, and a solid red line later in the summer. An inset hydrograph of the Upper Dearborn gage and Dearborn Highway 200 gage minus the flows from the Middle Fork are also presented for reference.

2007 Irrigation Season

The 2007 water year was the lowest captured by the study and USGS gaging records indicated that average monthly flows in June, July, August and September were in the historical lower quartile. Estimated canal diversions are considered to be reliable after June 10, 2007 when upper Dearborn flows dropped to about 300 cfs. The maximum estimated diversion after June 10 was 37 cfs on July 8. Late season flows at the Upper Dearborn site indicates that beginning August 7 to September 20, 2007 the Dearborn Canal was diverting approximately half of the flow of the Dearborn River. A hydrograph (Figure 24) of the estimated diversion into Flat Creek by the Dearborn Canal and measured Upper Dearborn and Flat Creek flows for 2007.

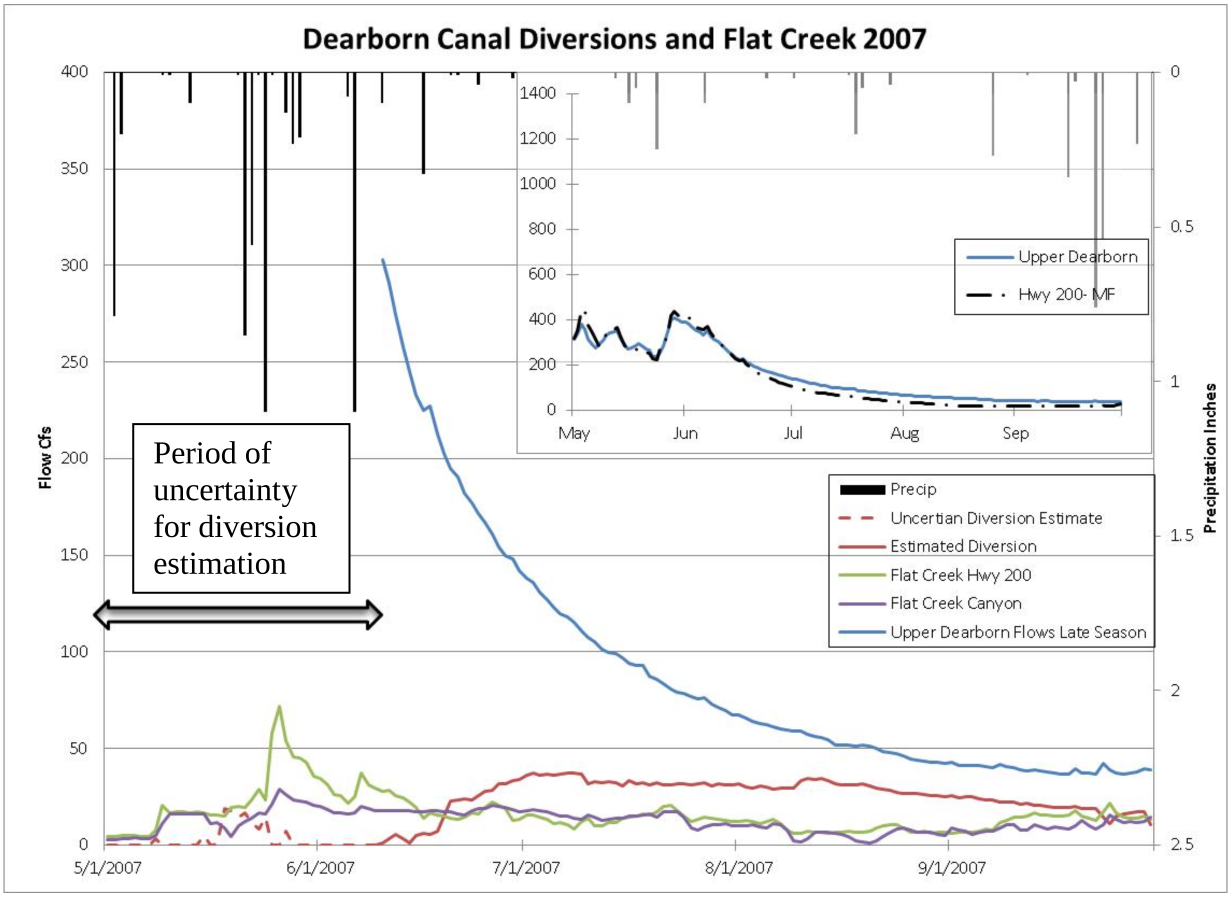

Figure 24: Graph of estimated diversions to Flat Creek by the Dearborn Canal and direct measurements of Flat Creek in 2007. Negative diversion flows are represented as zero.

Much of the water that is diverted by the Dearborn Canal is consumed before it reaches the Flat Creek gaging sites at Highway 200 and in the Canyon. In general an estimate of water lost from the system can be made by comparing the hydrographs of the estimated diversion (inflows) to the hydrograph of the Flat Creek Canyon site (outflows).

The hydrographs of the Flat Creek Highway 200 and Canyon sites are similar with the exception that flows at the Highway 200 site were higher in late May and early June. The hydrograph indicated that throughout the season water is lost and gained between the sites. This likely is the result of complexity in diversions, depletions, natural runoff and return flows from individual operations throughout the irrigation season along this reach of the stream.

The average flows from July 1 to September 31, 2007 at the Flat Creek Highway 200 and Flat Creek Canyon site were 12 cfs and 10 cfs respectively. Average flows indicated that, overall, there is a small net depletion of flow between the two sites.

2008 Irrigation Season

The 2008 water year was slightly below the long term average annual flow, even though there was a large flood event. Precipitation events added substantial flows to the system in May and June, consistent positive diversion estimates were made after July 14, when the Dearborn River dropped below about 150 cfs. A hydrograph (Figure 25) of the estimated diversion into Flat Creek by the Dearborn Canal and measured Upper Dearborn and Flat Creek flows in 2008.

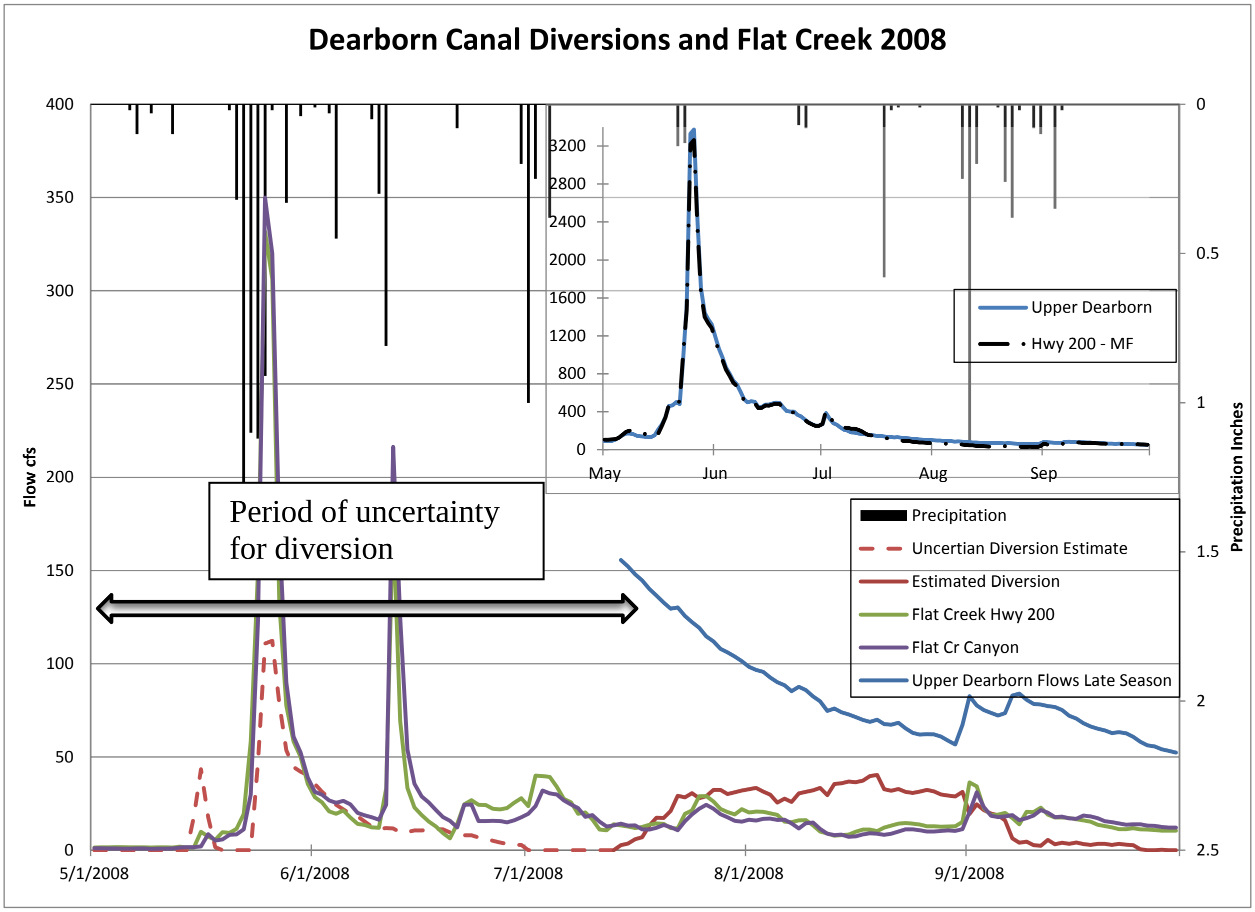

Figure 25: Graph of estimated diversions to Flat Creek by the Dearborn Canal and direct measurements of Flat Creek in 2008. Negative diversion flows are represented as zero.

The maximum estimated diversion after July 14 (the period of uncertainty) is 40 cfs on August 18. The estimated diverted volume drops dramatically on September 1 and remains low for the rest of September. The decrease in the diverted volume coincides with rising flows on the Upper Dearborn.   When the estimated diverted volume is compared to flows at the Upper Dearborn gage, it appears that the Dearborn Canal was diverting a significant portion of the Dearborn River flow from mid-July to September 1.

Large spikes from precipitation were observed in hydrographs of the Flat Creek Highway 200 and Canyon sites in 2008. The average flows from July 1 to September 31, 2008 at the Flat Creek Highway 200 and Flat Creek Canyon site were 17 cfs and 16 cfs respectively. There is a pattern of system gains and losses between the two Flat Creek sites. In general, a small amount of flows was depleted from the system between the Highway 200 and Canyon sites.

2009 Irrigation Season

The 2009 water year was slightly above the long-term average with above average monthly flows observed in May, August and September. Similar to 2007, diversion estimates after June 10 when the Dearborn River was flowing about 381 cfs, are considered reliable. A hydrograph (Figure 26) of the estimated diversion into Flat Creek by the Dearborn Canal and measured Upper Dearborn and Flat Creek flows in 2009.

Diversions of up to about 100 cfs were estimated for the later part of June with diversions generally declining for the remainder of the season. Spikes in Flat Creek flow and estimated diverted volume occur in late July and early August, which likely represent responses to precipitation events.

Due to overall higher flows, the estimated diversion in 2009 does not exceed more than approximately 25% of the water in the Dearborn River. This is the first year in the study where water supply conditions were favorable enough to meet diversion demands and have above average flows in August and September.

The hydrograph of the estimated diversion is higher than flows in Flat Creek from June 12 to July 16, 2009, and for the remainder of the season the estimated diverted flows are lower than flows measured in Flat Creek. The data indicate that water is lost between the diversion and Flat Creek Highway 200 for approximately one month. Precipitation events and elevated flow conditions in 2009 are likely causing the estimated diverted volume from the Dearborn River to be low.

The hydrographs of the Flat Creek Highway 200 and Canyon sites demonstrate a pattern of gains and losses between the two sites. The average flow from July 1 to September 31, 2009 at the Flat Creek Highway 200 and Flat Creek Canyon site was 22 cfs and 22 cfs respectively. Generally minor depletions were observed between the gages during 2009. The same average flows is likely due to the influence of the July precipitation events and higher flow at the Canyon sites during these events.

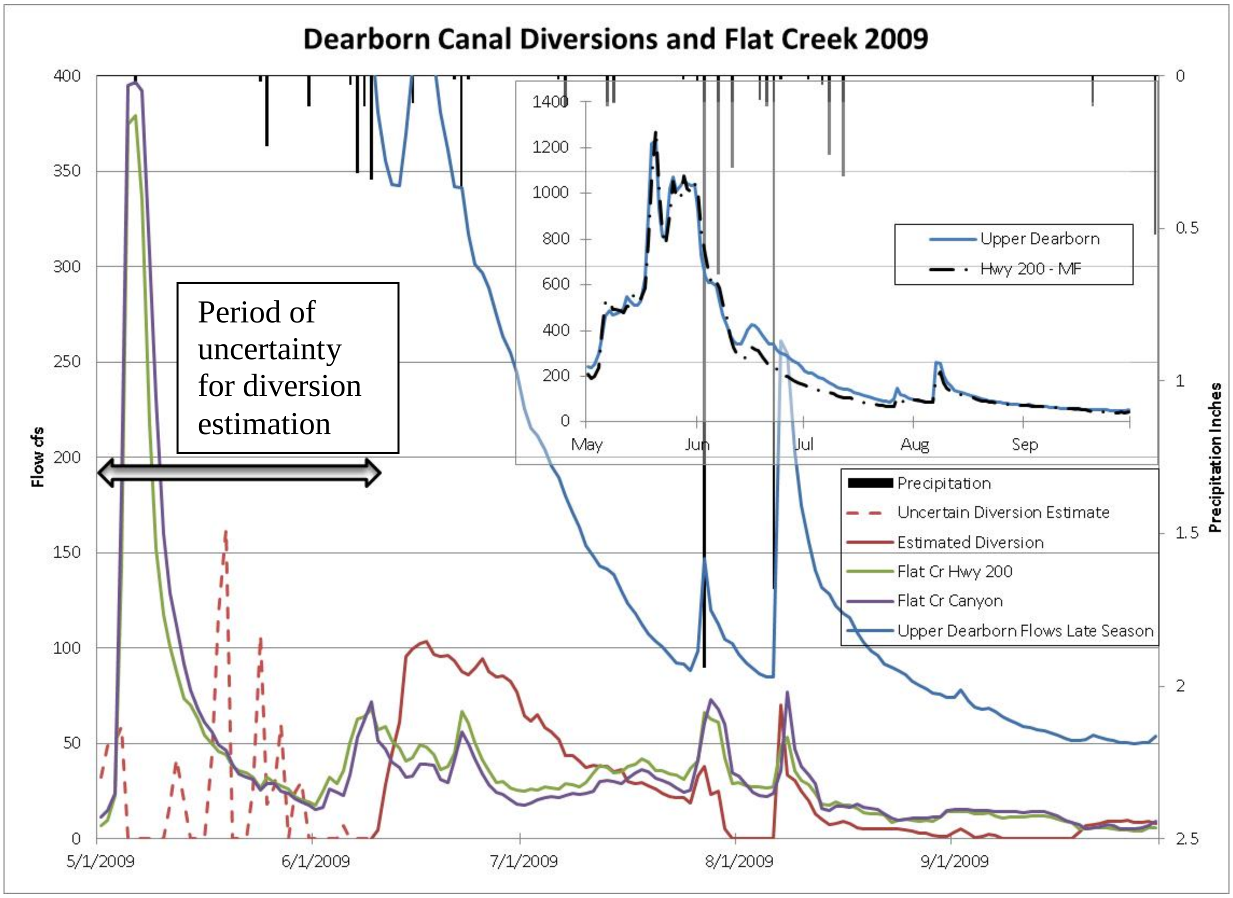

Figure 26: Graph of estimated diversions to Flat Creek by the Dearborn Canal and direct measurements of Flat Creek in 2009. Negative diversion flows are represented as zero.

2010 Irrigation Season

Streamflows during 2010 were generally below the long term average. Dearborn Canal diversion estimates for 2010 are considered reliable after June 4 when the Dearborn River was flowing at 520 cfs. A hydrograph (Figure 27) of the estimated diversion into Flat Creek by the Dearborn Canal and measured Upper Dearborn and of Flat Creek flows in 2010.

Estimated diversions peak at about 80 cfs during early June then generally decline until late July, at which time the diversion remains fairly consistent at approximately 17 cfs. The estimated diverted flow is zero (negative) for a short period of time in late August/early September (possibly due to a precipitation event) and then remained fairly constant near the late summer 17 cfs rate until September 31.

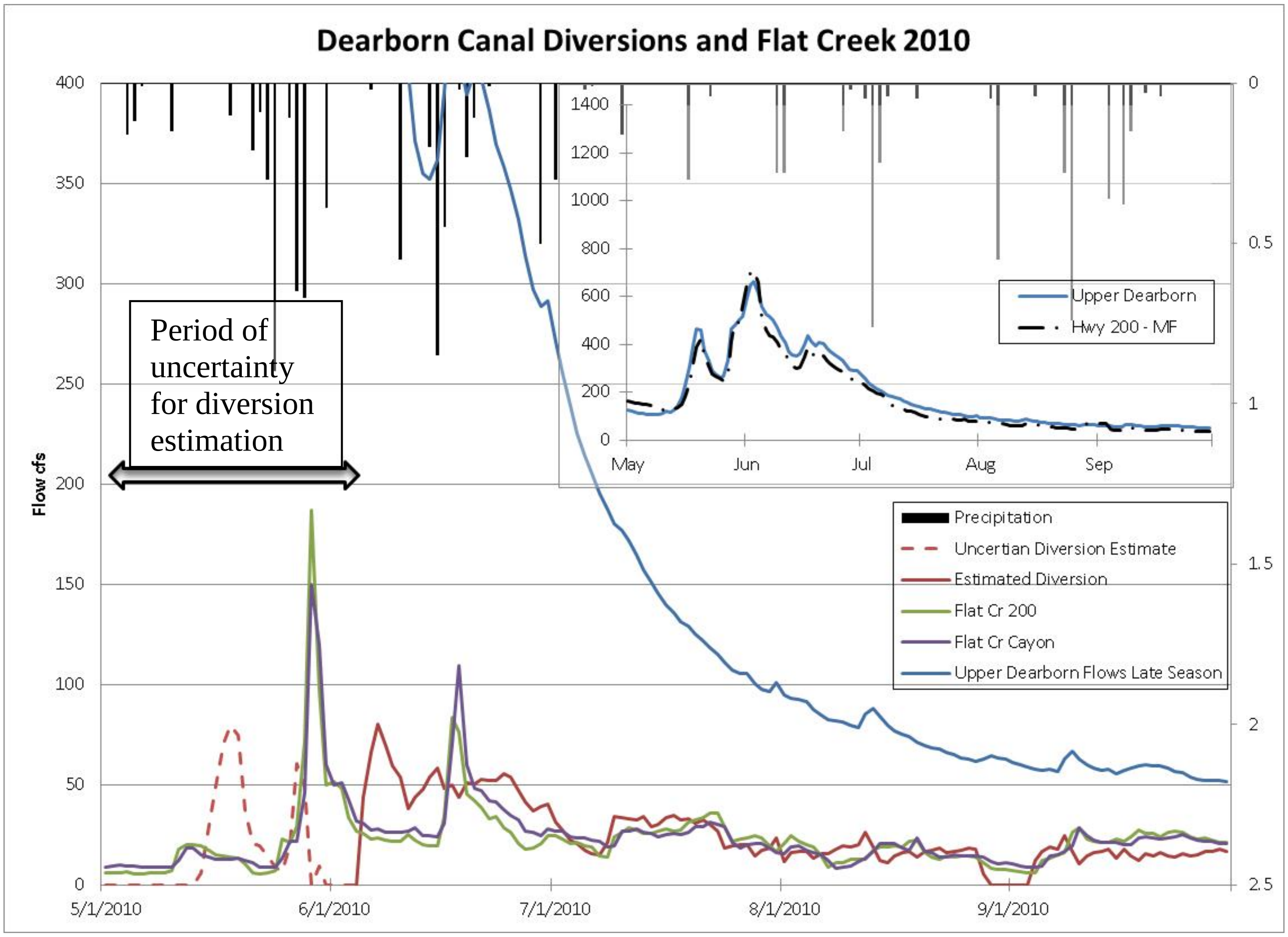

Figure 27: Graph of estimated diversions to Flat Creek by the Dearborn Canal and direct measurements of Flat Creek in 2010. Negative diversion flows are represented as zero.

The estimated diverted volume in 2010 closely follows the hydrographs of the Flat Creek gage sites except from June 5th to July 2nd when diverted flows were estimated to be higher than flows in Flat Creek from June to mid-July. The estimated diversion was both higher and lower than flows in Flat Creek for the remainder of the year.

Summer precipitation resulted in above average August flows in 2010. Water supply conditions declined into September at which point the Dearborn diversion continued to divert a consistent volume.

The hydrographs of the Flat Creek Highway 200 and Canyon sites demonstrate a pattern of gains and losses between the two sites. The average flows from July 1 to September 31, 2010 at the Flat Creek Highway 200 and Flat Creek Canyon site was 20 cfs and 20 cfs respectively. The hydrograph and seasonal average indicate that in 2010 the two Flat Creek gages were stable and that there generally minor depletions of flow between the two sites. The same average flows are likely due to the influence of August and September precipitation events.

Estimated Irrigation Diversions and Depletions

In addition to the irrigation on Flat Creek, approximately 1,400 acres are irrigated from the Middle Fork, South Fork and along the mainstem of the Dearborn (Figure 23). Because DNRC gages on the Middle Fork and South Fork drainages were located below the majority of irrigated acres, irrigation depletions on these tributaries could not be estimated using gaging data. Depletions along the mainstem of the Dearborn were difficult to estimate with gaging data due to the: magnitude of flow being large relative to depletions, the distance between gages, and the presence of ungaged tributaries.

Given these difficulties, DNRC gaging records were used to estimate annual irrigation depletions only for the Flat Creek drainage. Water consumption was estimated using remote sensing data for the year 2007 for the entire drainage, including Flat Creek.

Dearborn Canal and Flat Creek

The estimated monthly and seasonal volumes of Dearborn River water diverted by the Dearborn Canal are presented in Table 8. The July 1st to September 31st estimated diverted volume averaged 3,616 af over the study period. The 2007 diverted volume estimate of 5,043 af is considered to be the most accurate estimate of all of the study years, due to the lack of precipitation events and stable flow conditions. However, 2007 was the driest year of the study period and it's likely that the irrigation demand was higher in 2007 than during an average precipitation year, although the available water supply was less.

Estimated Dearborn Canal Diversion in Acre-Feet				
	July	**August**	**September**	**July -Sept Diversion**
2007	2,036	1,830	1,177	5,043
2008	776	1,982	369	3,127
2009	2,151	577	229	2,956
2010	1,589	899	848	3,336
Average	1,638	1,322	656	3,616

Table 8: Estimated volumes of water diverted by the Dearborn Canal.

Irrigation depletions in Flat Creek between the Dearborn Canal and highway 200 were estimated using daily mean flow from: (1) Dearborn Canal diversion estimates, (2) gaged Flat

Creek highway 200, and (3) estimated natural Flat Creek flows. Irrigation depletions were estimated between Flat Creek Highway 200 and Flat Creek Canyon from gaged flow data at those monitoring sites. There is no irrigation on Flat Creek below the Canyon gage.

The estimated depleted volume in the Upper Flat Creek drainage carries uncertainly due to the estimated Dearborn Canal diverted volume being used in the depletion calculation. Estimates in the Lower Flat Creek drainage (Flat Creek at Hwy 200 and at the Canyon) are from direct measurements and do not have the same uncertainty. Estimated depletions in the Upper Flat Creek and Lower Flat Creek drainage are presented separately in Tables 9 and 10 to help provide a better understanding of water use in the basin and the problems encountered with estimation of water use without direct measurement of diverted volumes.

Estimated Depletions: Upper Flat Creek (Dearborn Canal Headgate to Flat Creek Hwy 200) in Acre-Feet				
	July	August	September	July -Sept Loss
2007	-1,224	-1,331	-401	-2,955
2008	356	-1,180	580	-244
2009	-31	591	276	836
2010	-180	-8	323	136

Table 9: Depletions from Dearborn River from irrigation in the Upper Flat Creek Drainage by month. Note: negative values indicate depletions, positive values indicate flow gains. Data from May and June is not presented due abovementioned uncertainty.

Estimated Depletions: Lower Flat Creek (Flat Creek Hwy 200 to Flat Creek Canyon) in Acre-Feet						
	May	June	July	August	September	May -Sept Loss
2007	-573	-229	18	-127	-208	-317
2008	82	309	-150	-135	23	-263
2009	873	-450	-232	78	94	-60
2010	-47	355	-39	-10	-43	-92

Table 10: Depletions from Dearborn River from irrigation in the Lower Flat Creek drainage by month. Note: negative values indicate loss of water.

Monthly net depletions in the Upper Flat Creek drainage range from a loss of 1,331 af (August 2007) to a gain of 591 af (August 2009). July-September depletions range from a depletion of 2,955 af to a gain 836 af to service Approximately 3,277 acres of irrigation.

Gains in water from the Dearborn Canal to the DNRC gage at Highway 200 are possible due to precipitation-generated natural flow, irrigation shut off and return flows. However, these "gains" of water most likely represent an incorrect estimation of the Dearborn Canal diversion. Depletions are summed for the months of July through September when confidence is higher for a more accurate estimate.

The summed July-September volume in 2009 and 2010 indicate an overall gain in water. The data for 2008-2010 in the Upper Flat Creek drainage likely underestimates actual depletions from the system as estimated gains are likely a byproduct of indirect measurement of the diverted volume.

Depletions in the Lower Flat Creek drainage are based on actual measurement at two DNRC gages on Flat Creek. Gains in water were observed during the irrigation season especially during May and June. These gains are likely due to precipitation adding natural flow to Flat Creek and irrigation practices including: shut off of irrigation for haying, ditch water bypassing the Highway 200 gage and return flows. Overall from July 1st to September 31st the maximum depletion was 317 af and an average seasonal depletion of 183 af. Approximately 728 irrigated acres exist along this section of the drainage.

Overall, it was difficult to accurately estimate depletions in the Flat Creek drainage using a water balance approach because Dearborn Canal diversions and Flat Creek natural flow inputs were not directly measured.

Estimation of Irrigation Water Consumption Using Remote Sensing

Water consumption (ET) evapotranspiration was estimated for 2007 using remote sensing techniques to give a reasonable approximation of the amount of water that might be consumed by ET by irrigated crops and the overall level of irrigation service for the basin (table 11). Appendix C describes the remote sensing method in more detail.

For the Flat Creek drainage, the overall remote-sensing computed depletions are higher than the gaging-based estimation due to the longer estimation season (including data for May and June) and reduced likelihood for accumulated error. The remote sensing technique in the Flat Creek drainage estimated 5,977 acre feet of depletion during 2007; the gaging data technique estimated a depletion of 3,272 acre feet. Irrigated lands in the Flat Creek drainage were estimated to consume 1.42 acre-feet of water per acre (af/acre) during 2007 based on the remote sensing technique.

Irrigated lands in the South Fork were estimated to have the lowest depletion per acre 0.70 ft/acre and the Middle fork was estimated to have the highest depletion of 1.74 ft/acre. The level of irrigation service can be estimated by the amount of water consumed per acre. The Middle Fork and Flat Creek drainages appear to have the highest level of service in the watershed.

The overall irrigation depletion for the watershed in 2007 was estimated to be 7,905 acre feet or 1.01 feet of water consumed per acre irrigated. The highest estimated consumption of water was for the Flat Creek drainage at 5,977 acre-feet.

Remote Sensing Estimation of Irrigation Season ET for 2007			
Area	**May 1st to September 30th ET 2007 (AF)**	**Irrigated Acres**	**Depletion/Acre**
Flat Creek	5,977	4,206	1.42
Middle Fork Dearborn	811	465	1.74
South Fork Dearborn	333	556	0.60
Mainstem Dearborn	292	415	0.70
Auchard Creek	491	623	0.79
Total/average	7,905	6,265	1.05 *

Table 11: Irrigation depletions and diversions by drainage.

The remote sensing depleted volume for the Flat Creek drainage was 934 acre-feet greater than the volume that was estimated to be diverted in 2007 using stream gaging data. Dearborn canal diversion data from May and June 2007, if it were available, would be expected to increase the total diverted volume. Estimated Flat Creek natural flows (1,700 acre-feet May 1st to Sept 30th,2007) are expected to reduce the need for imported water from the Dearborn River.

Data from the Soil Conservation Service (SCS, now known as Natural Resource Conservation Service) provides a method for estimating irrigation diversions based on crop consumptive use and system efficiency. The “Water Conservation and Salvage Report for Montana” indicates that in Lewis and Clark county in 1978: the ditch conveyance efficiency was 52% (48% of the diverted water was lost in irrigation ditches) and the farm efficiency was 43% for flood irrigation (57% of water applied to a field was not consumed). The farm efficiency of center pivots was estimated as 80% percent (Ashley and Others). However, much of this “lost” irrigation conveyance and farm delivery water will eventually come back to the system as return flow.

For example: if a flood irrigated crop consumed 100 acre-feet: the volume applied to the field would be 233 acre feet and the volume diverted would be 447 acre feet. Approximately 79% or 3,209 irrigated acres in the Flat Creek drainage are expected to be irrigated at 43% efficiency (because these acres are flood/other sprinkler irrigated) and 21% or 829 irrigated acres are expected to be irrigated at 80% efficiency (center pivot irrigated acres). The overall field efficiency in the drainage (based on the combination of flood and sprinkler irrigation) is expected to be about 50%.

The SCS data-based diversion estimates are for the summation of all diversions in the Flat Creek drainage and cannot be used as an estimate of the total Dearborn Canal diverted volume. This is because the method does not take into account that return flow water in Flat Creek is reused and recycled as it flows downstream, especially with flood irrigation. Simply using the summation of the diversionary requirements would overestimate the amount of water that was imported from the Dearborn River.

Irrigation Water Use

Generalized 2007 Dearborn watershed irrigation water use is illustrated in Figure 28 using the following data:

1) Water estimated to be consumed by evapotranspiration using (ET) remote sensing data;
2) Gage Inflows; Upper Dearborn, Middle Fork Dearborn, South Fork Dearborn, and estimated Flat Creek natural flows;
3) Gaged Outflows for Flat Creek Canyon and Dearborn Mouth;
4) Estimated 2007 Dearborn Canal diversions;

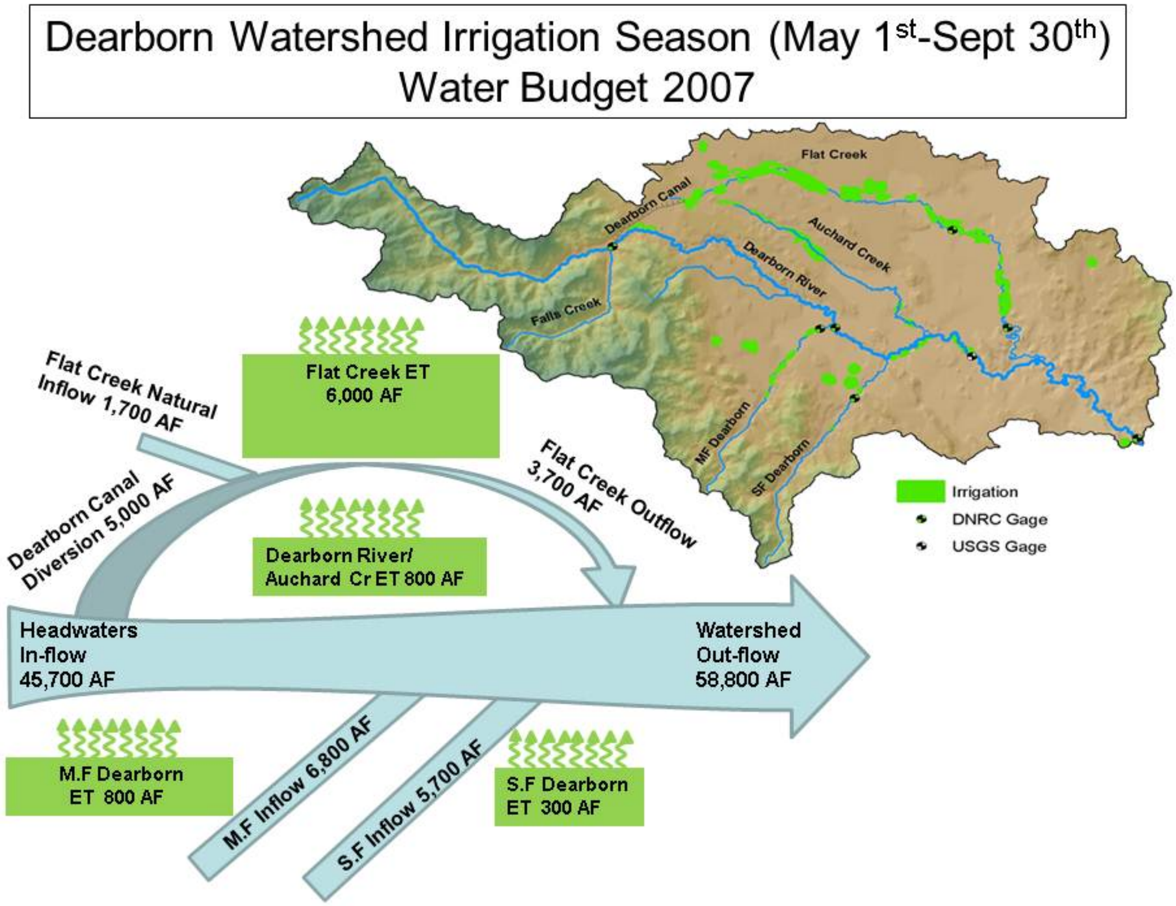

Figure 28: Generalized water use in the Dearborn watershed in 2007.

The conceptual diagram of water use indicates that inflows are greater than outflows. Mass balance is not achieved in the diagram due to ungaged tributaries and ground water inflows.

The 2007 estimated gaged diversion (5,000 acre-feet Jul 1st to September 30th) plus the estimated Flat Creek natural flow 1,700 acre-feet is likely not sufficient to meet the irrigation demand and produce 3,700 acre-feet of outflow from Flat Creek. In order for the numbers to balance, about 2,900 acre-feet would have needed to have been diverted through the Dearborn Canal during May and June. This would equate to an average canal diversion of about 24 cfs, which is similar to the 28 cfs computed average diversion for the July through September period.

Water use in the Dearborn during the lowest water supply year (2007) of the study period shows that about 13% of the total basin surface water supply was consumed by irrigation. Diversion estimates were limited to the Dearborn Canal from July 1st to September 30th, 2007. The diverted volume was estimated to be 47% of the water supply during that time period. The diverted volume is expected to be underestimated and is likely closer to twice the consumed volume based on conveyance and field efficiencies. Diverted and consumed percentage is expected to increase during the low water supply months of August and September. It is unclear how the diverted and consumed volumes will change under higher water supply conditions.

Water Temperature Monitoring

The Dearborn River has been identified by the DEQ TMDL process as being thermally modified, meaning human use is altering water temperatures. Water temperature data were collected by the DRNC during the study period at all stream gaging sites.

Water temperature can be affected by a wide variety of factors including but not limited to: vegetative cover, gage location, groundwater/surface water interactions, irrigation return flows, and temperature sensor depth.

Surface water temperature was recorded on the Dearborn River at the Upper Dearborn, Highway 200, and Dearborn Mouth sites. Temperature data were obtained from USGS gage 6073500 at Highway 287 where water temperature has been collected since 1993. Water temperatures in the Dearborn River follow seasonal and daily diurnal trends (figure 29). The erratic changes in temperature suggest that water temperature is heavily influenced by daily changes in ambient air temperature.

The general seasonal temperature pattern of the Dearborn River is as follows: cool water temperatures are observed in April and May. Water temperatures rise from May to July/early August when daytime air and water temperatures peak for the season. Water temperatures cool from August to September following seasonal air temperature trends and the decreases in daylight.

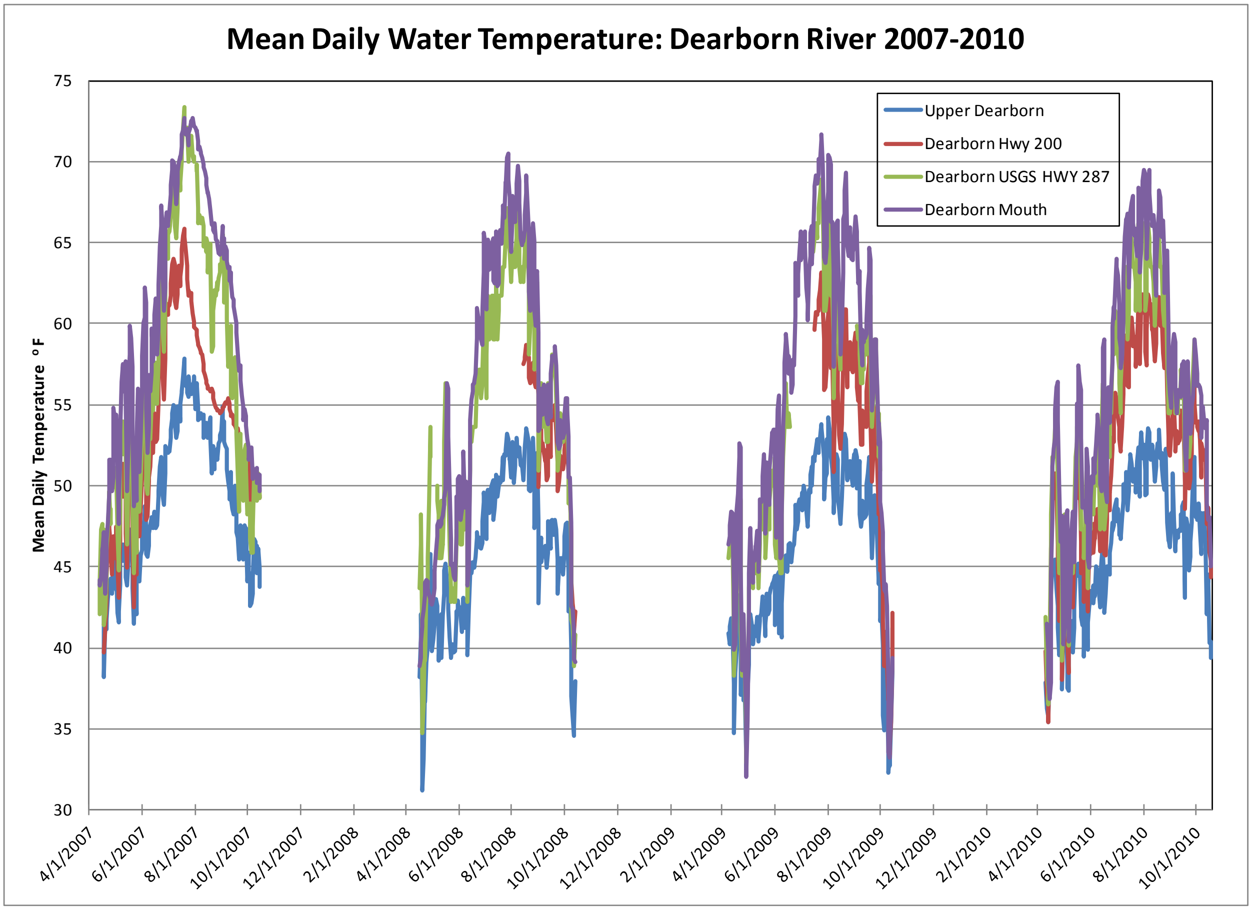

Figure 29: Mean daily water temperature of the Dearborn River DNRC gaging stations and the USGS Highway 287 gaging station for all study years.

As expected, the Upper Dearborn site has the coolest temperatures. The Upper Dearborn site is located at the highest elevation, is closest to the headwaters and is unaffected by irrigation withdrawals. Water temperatures on the Dearborn River were observed to increase downstream with the warmest temperatures at the mouth of the river. Water temperatures measured downstream of the Upper Dearborn site also appear to be more sensitive to daily air temperature changes.

Warming of the Dearborn River water is expected as distance increases from the mountainous headwaters and the elevation decreases. The largest temperature disparity (up to 20 or more degrees Fahrenheit (^{o}F) is observed between the Upper Dearborn site and downstream sites in the river, when water temperatures are the warmest in July and August.

Surface water temperatures were recorded at the Middle Fork, South Fork, Flat Creek Highway 200, and Flat Creek Canyon gaging stations. Seasonal temperature patterns similar to that of the Dearborn River can be seen in the tributaries (Figure 30). The South Fork shows a less erratic signal indicating that groundwater contributions may be moderating water temperatures.

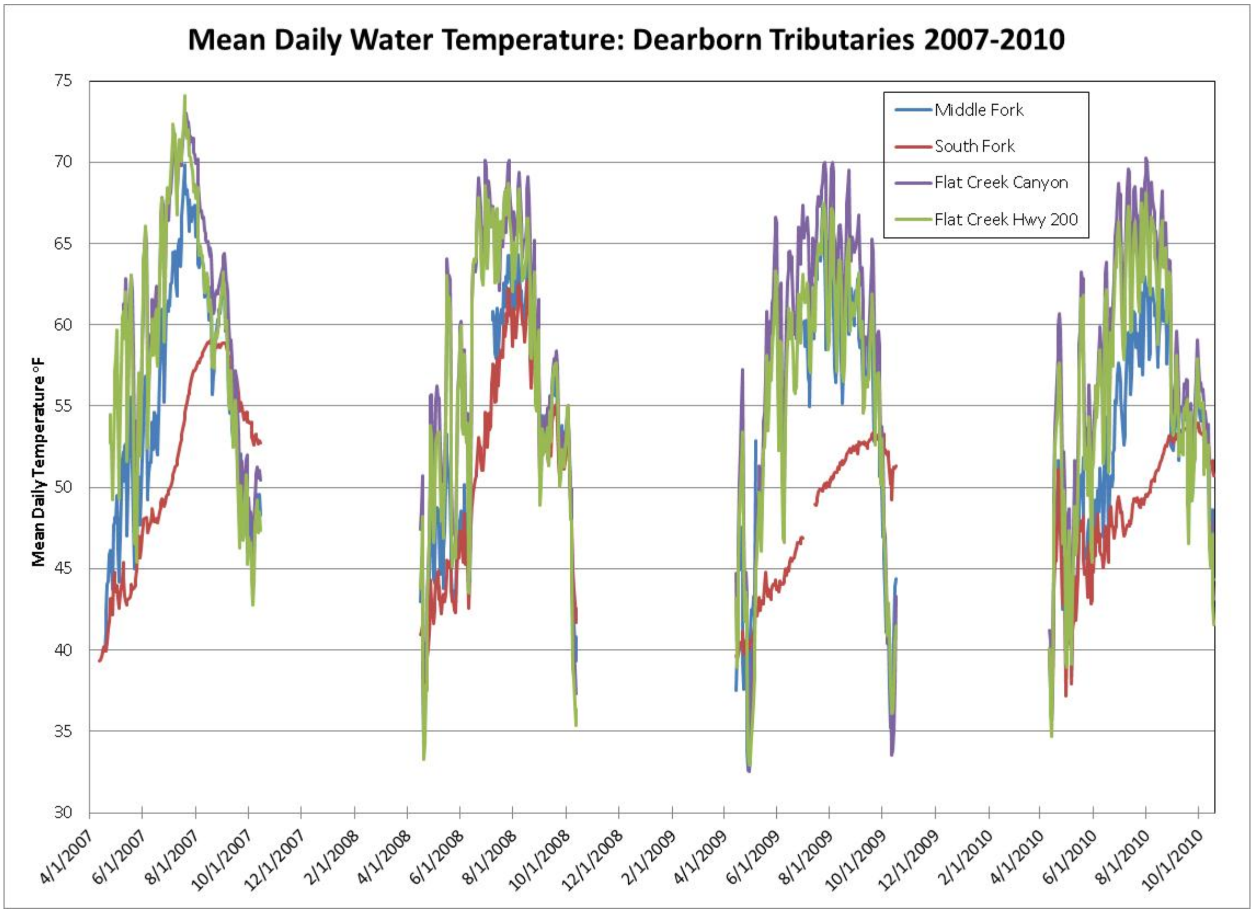

Figure 30: Mean daily water temperature of Dearborn River tributaries.

Water temperatures recorded at the South Fork gage was the coolest of all the tributaries measured and the Flat Creek Canyon site was the warmest. In general, temperatures observed on the Middle Fork were cooler than temperatures observed in Flat Creek. However, Middle Fork temperatures were considerably warmer than temperatures observed on the South Fork. Water temperatures observed in Flat Creek Canyon indicated a very similar temperature trend at Flat Creek Highway 200 with water temperatures being slightly cooler at the up-gradient Highway 200 site. Water temperature signals observed in Flat Creek demonstrate a very erratic daily pattern influenced by daily ambient air temperature and likely intensified surface return flows from flood irrigation practices in the Flat Creek drainage.

Temperature Comparability

Resource managers monitor water temperatures on the Dearborn River during the summer months because high water temperatures can impact aquatic life. Continuous temperature monitoring is conducted by the USGS at the Highway 287 gage with a period of record extending back to 1993. Temperature data collected at the USGS gage reflect temperature conditions representative of the lower river. Since temperature can be influenced by a large number of factors, a statistical comparison between data collected at the USGS gage and temperature data collected by the DNRC was not done.

However, a simplified comparison between the sites was completed, and is presented as a tool to estimate the temperature of inflows and outflows to the system during the peak temperature months of July and August:

1) The daily mean water temperature at the Upper Dearborn site is estimated to be 12^{0}F colder than the daily mean water temperature at the USGS gage. The daily maximum temperature is also estimated to be 12^{0}F colder at the Upper Dearborn site than at the USGS gage.

2) The daily mean temperature is estimated to be 2.6^{0}F warmer at the Dearborn Mouth site than the USGS gage. The maximum daily temperature is estimated to be 0.7^{0}F warmer at the Dearborn Mouth site as compared to the USGS gage.

Streambed Temperature Monitoring

Streambed temperature monitoring was conducted at the Upper Dearborn, Dearborn Highway 200, Dearborn Mouth, Middle Fork Dearborn, South Fork Dearborn, Flat Creek Highway 200 and Canyon sites in 2007 and 2008. Instrumentation was lost at the Upper Dearborn and Dearborn Highway 200 sites during the flooding event in 2008 and temperature sensors were not replaced.

Streambed temperature results yielded inconclusive results and the data are presented in Appendix D. Data are presented to provide qualitative information about near surface groundwater and surface water interactions at the gaging sites. Further study and mathematical analysis would be required to better understand how the Dearborn River is interacting with the shallow groundwater system. Streambed temperature data have been reduced to daily maximums and minimums for simplicity during graphing.

Surface Water Temperature and Aquatic Life

Elevated water temperatures have been documented to harm cold water fish species. Native trout species such as westslope cutthroat trout have lower tolerances to elevated temperatures than introduced species such as rainbow trout (Bear 2005). The predominate trout species in the Dearborn River is rainbow trout.

The upper limit of the optimal growth temperature for rainbow trout is 65 ^{0}F (Bear 2005). Short term exposure to water temperatures greater than 75^{0}F has been shown to be lethal to rainbow trout (Bear 2005). Water temperature collected at all stream gaging sites has been summarized to indicate the number of days above 65^{0}F and 75^{0}F.

The number of days over the study period where the maximum daily temperature reached or exceeded 65^{0}F is presented in figure 31. Temperature data were unavailable at the Highway 200 site from May to mid-August 2008 which likely underestimated the number of days where the maximum daily temperature reached or exceeded 65^{0}F in 2008.

The number of days the maximum temperature met or exceeded 65^{0}F increased on the mainstem of the Dearborn from the headwaters where the Upper Dearborn site had zero days above 65^{0}F to the Dearborn Mouth site where the maximum number of days at or above 65^{0}F was observed (84).

The South Fork of the Dearborn had the lowest number of days (0) at or above 65^{0}F of all the tributaries. Both the Flat Creek sites had 70 plus days when the maximum temperature met or exceeded 65^{0}F (0).

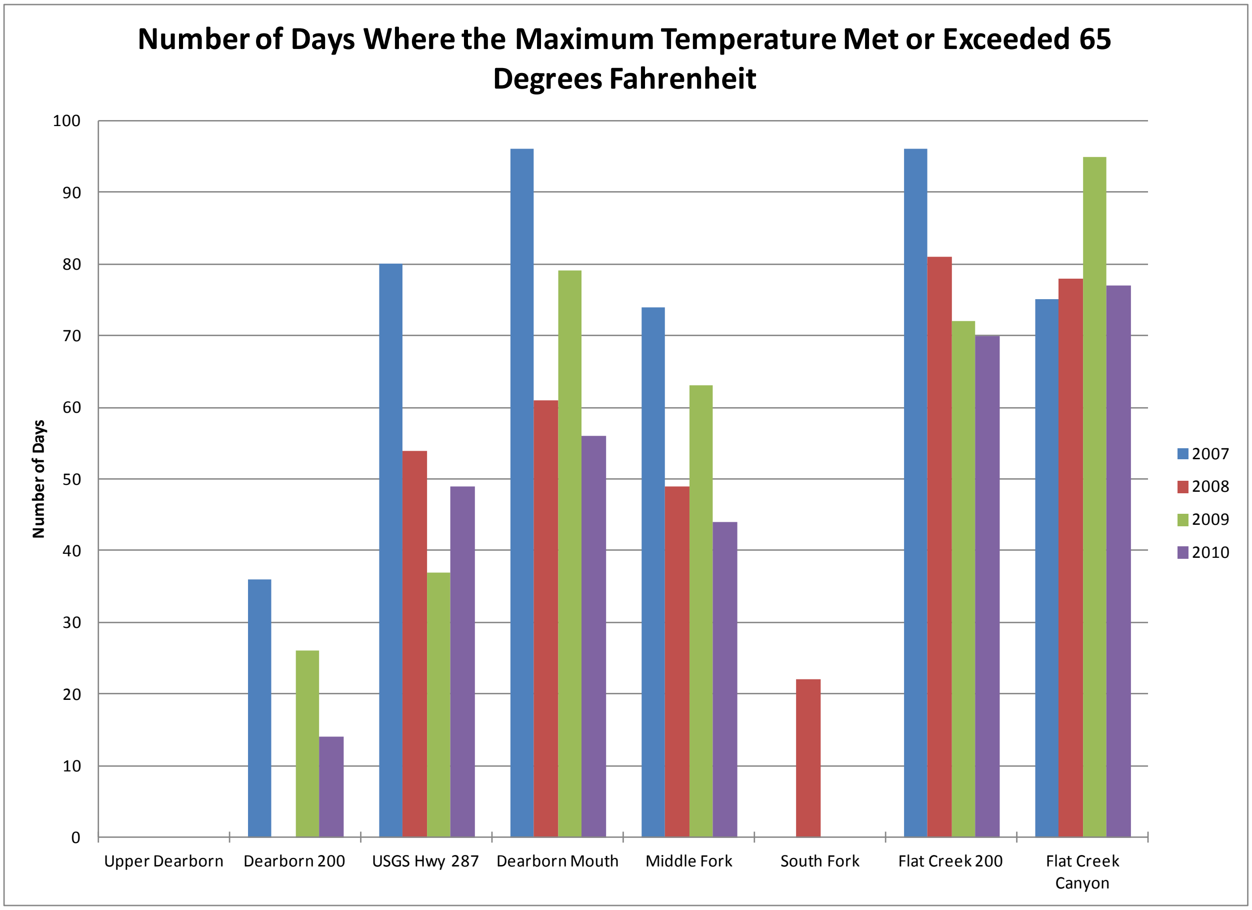

Figure 31: Number of days where the maximum daily temperature met or exceeded 65 degrees Fahrenheit.

The number of days over the study period where the maximum daily temperature reached or exceeded 75^{0}F is presented in figure 32. Temperature data were unavailable at the Highway 200 site from May to mid-August 2008, therefore temperature threshold exceedance for the Highway 200 site is incomplete for 2008.

Water temperatures reached or exceeded 75^{0}F on the lower stretches of the Dearborn River at the USGS Highway 287 gage and at the Dearborn Mouth site. The Dearborn Mouth site consistently had days when the temperature met or exceeded 75^{0}F over the study period. The Middle Fork Dearborn, Flat Creek Highway 200 and Flat Creek Canyon also had days over the study period when temperature met or exceeded 75^{0}F over the study period.

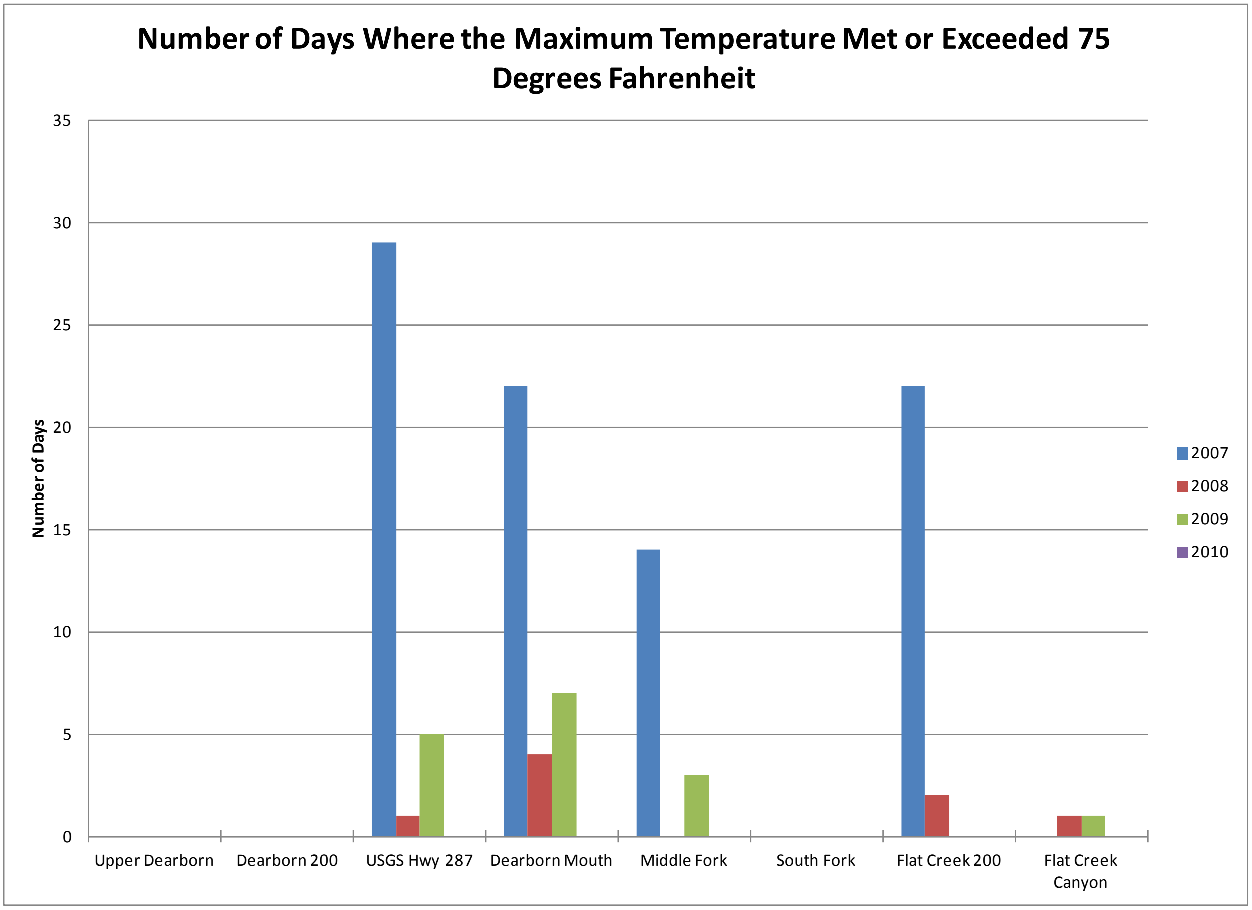

Figure 32: Number of days where the maximum daily temperature met or exceeded 75 degrees Fahrenheit.

In general, water temperatures were highest during the 2007 monitoring season which coincided with some of the lowest stream flows and warmest air temperatures during the study period. In 2007, there were more days when maximum water temperatures on the mainstem Dearborn River and tributaries were greater than 75^{0}F than all the other years of the study period combined.

The temperature data presented in relation to cold water fisheries optimum growth and survival shows that favorable conditions for trout existed all years at the Upper Dearborn site and all years except for a brief period during 2008 at the South Fork of the Dearborn site. Optimum growth temperatures were exceeded on most years at the Highway 200 gage and on all years at the USGS Highway 287, Dearborn Mouth, Middle Fork Dearborn, Flat Creek Highway 200 and Flat Creek Canyon sites.

Short term temperature exposure limits were exceeded at the USGS Highway 287, Dearborn Mouth, Middle Fork Dearborn, Flat Creek highway 200 and Flat Creek Canyon site on two or more years during the study period.

Summary

Dearborn Watershed Streamflow Characteristics

Hydrographs of the Dearborn River and its tributaries reflect the seasonal pattern of the snowmelt dominated runoff system. The majority of water for the gaging season (May through September) moves through the system during runoff in May and June. Base flow conditions are generally observed from August to April. The Flat Creek hydrograph stands out from the rest of the system as the flow regime is altered by the addition of Dearborn River water from the Dearborn Canal.

In general, as the distance increased from the headwaters, perennial and ephemeral tributaries contributed to the increased flow in the Dearborn River. Irrigation depletions and return flows from the river were observed through gaging at specific locations in the watershed.

Flow Contributions of Tributaries

The headwaters of the Dearborn River contribute 76% of the river's flow. The Middle Fork drainage contributes 13% and the South Fork contributes slightly less with 9%. The flow contribution of Flat Creek (without the addition of the diverted Dearborn River water) is estimated to be 2%.

Streamflow and Water Supply Conditions

Streamflow and precipitation over the study period indicated below average stream flow and mountain snowpack in 2007 and 2010. Above average snowpack and stream flow in 2009 and average snowpack and slightly below average flows in 2008. The 2007 water year had the lowest water supply conditions and 2009 had the highest over the study period.

The most significant event captured during the study period was the 2008 flood, recorded to be the fifth largest peak flow to date at 5,150 cfs (20 year event) USGS gage Dearborn River near Craig.

System Gains and Losses

Synoptic measurements along the Dearborn River provide a snapshot of the system gains and losses. In general, during the summer months of July, August, and September, the mainstem of the Dearborn River loses water (primarily to diversion) from the Upper Dearborn gage to the

USGS gage at the Highway 287 Bridge. The river gains water from the Highway 287 Bridge to the mouth. Gains and losses were not quantified in the Middle and South Forks of the Dearborn during synoptic runs. The presence of ungaged irrigation diversion, ungaged tributaries and long distances between gage sites limits the ability of synoptic measurements to give insight into ground water and surface water interactions of the river.

Irrigation Water Use

The beneficial use of water for irrigation is an integral part of the hydrology of the Dearborn watershed.   The majority of irrigated lands (approximately 4,045 acres or 65%) exist in the Flat Creek drainage. Irrigated lands in Flat Creek are primarily serviced by water from the Dearborn River via the Dearborn Canal. The South and Middle Forks of the Dearborn River contain approximately 566 and 475 acres of irrigation respectively. Irrigated lands along the Dearborn River are limited to 381 acres due to the topography of the land.

Irrigation water use was quantified using two methods: stream gaging data and remote sensing technology.

Stream gaging was not adequate to quantify irrigation water use in the mainstem of the Dearborn River below Highway 200, and the South and Middle Forks of the Dearborn River. The Dearborn Canal diversion was indirectly measured using gaging data from the Dearborn River above and below the diversion.

Estimation of the amount of water diverted and consumed via the Dearborn Canal proved to be difficult during the elevated flow conditions and precipitation events. The average July 1st to September 30th diversion was 3,316 af or 0.89 ft/r acre. The estimated diverted volume was highest during 2007 (during the lowest water supply year) and lowest in 2009 (during the highest water supply year). The diversion was estimated to take a significant portion of the total Dearborn flow volume in low water supply/high irrigation demand months in 2007, 2008 and 2010. Diversions of 1 to 33 cfs were computed during synoptic flow measurements.

The average computed consumed volume of water in the Flat Creek drainage over the study period was 740 af or 0.18 ft/ acre. Estimated consumption from July 1st to September 30th ranged from 3,272 af (2007) to 776 af (2009). The data indicate that consumption was highest during the lowest water supply conditions and lowest (indicating a gain of water) during the highest water supply conditions of the study. The accuracy of the consumption data are limited by indirectly measuring the diversion.

The remote sensing analysis of ET in 2007 (May 1st to September 30th) estimated depletion in the Flat Creek drainage of 5,977 acre feet (1.42 ft/acre) and a watershed depletion of 7,905 acre-feet (1.01 ft/acre). The estimated remote sensing depletion in the Flat Creek drainage was 2,705 acre feet higher than that based on the 2007 stream gaging data but the stream gaging data did not include May and June consumption for Flat Creek above Highway 200.

The Flat Creek drainage was estimated to have the largest depletions in the watershed followed by the Middle Fork and South Fork drainages. The highest level of irrigation service, estimated by the amount of water depleted per acre, were the Middle Fork and Flat Creek drainages.

The 2007 water year was well below average and remote sensing provided baseline estimates of the amount of water that was consumed by evapotranspiration. Additional remote sensing analysis during average water supply years would better quantify consumption during better water supply conditions.

Water use in the Dearborn during the lowest water supply year (2007) of the study period shows that 13% of the water supply is consumed by irrigation. Diversion estimates were limited to the Dearborn Canal from July 1st to September 30th, 2007. The diverted volume was estimated to be 47% of the water supply during that time period.

The diverted volume is expected to be underestimated and is likely closer to twice the consumed volume based on conveyance and field efficiencies. During the low water supply months of August and September the consumed portion of water will likely increase. It is unclear how the diverted and consumed volumes will change under higher water supply conditions.

Temperature Monitoring

Surface water temperature data were collected at all gaging stations over the study period. Streambed temperature data were collected in 2007 and 2008. In general, water temperature at all sites followed a seasonal trend influenced by ambient air temperature and length of daylight. Water temperatures in the Dearborn River were coolest near the headwaters and warmest at the mouth. The South Fork was the coolest tributary followed by the Middle Fork, and Flat Creek was observed to be the warmest. The cool temperatures on the South Fork are likely a function of local groundwater seepage.

The USGS gage can be used to provide reference conditions for locations throughout the water shed. The maximum daily water temperature at the Upper Dearborn site averages about 12^{o}F cooler than the USGS gage and the Dearborn Mouth site averages about 2.6^{o}F warmer during the summer months.

Streambed temperature data yielded inconclusive results. In general no strong interactions between surface and ground water were noted, except possibly for the South Fork. Streambed temperatures suggested that at some sites as the depth of water in the river changed that the interaction with the shallow groundwater system changed. A more detailed study would be needed to reach a more defined conclusion other than the general trends that were observed.

During the study period every site except the Upper Dearborn had multiple days that exceeded temperature thresholds for cold water fish species. Temperatures above 65^{o}F and 75^{o}F are outside of the optimal growth range and have been documented to be lethal to rainbow trout. During the study period thresholds for cold water species indicated that except for the upper reaches of the river (above Highway 200) and the South Fork, the temperature conditions are not favorable for trout growth during the hottest period of the summer months and that lethal conditions are reached in certain areas of the lower reaches of the river about three out of four years.

The temperature data represent conditions near the gages and, due to the dynamic nature of temperature and complex interactions in the river, the presented temperature data may not represent all of the thermal conditions present in the Dearborn River. The results of this study provide a generalized indication of temperature conditions and documented thresholds for cold water species impairment.

Conclusions

In conclusion below average streamflow and snowpack conditions were present two out of four years during the study period. During the months of July, August and September flows in the Dearborn River were typically below average. The beneficial use of water in the South Fork and Middle Fork drainages was not quantified using stream gaging data. However, gaging below the diversions in these drainages indicates that water use in these drainages is managed to allow these streams to flow year round.

Without direct measurement of diversions the utility of estimated diversionary use is limited. Remote sensing data provided an estimate of water use (7,905 acre-feet) for the year 2007, during low water supply conditions. The diverted volume is expected to be twice the consumed volume based on local conveyance and field efficiencies. However, further study would be needed to quantify water use during higher water supply conditions.

The major water use in the watershed is irrigation in the Flat Creek drainage. Diversions into Flat Creek were estimated be as high as 47% of the Dearborn River water supply during the low flow months of July, August and September, 2007.

Diverted water not consumed in the Flat Creek drainage returns to the Dearborn River approximately 28 miles below where it was diverted. The Dearborn Canal diversions might also function as carriage water and thereby lead to the more effective use of the natural flow of Flat Creek.

Temperature conditions in the river warm from headwaters to the mouth, making conditions during the hottest summer months unfavorable for cold water species from around the Highway 287 downstream to the confluence with the Missouri River.

Recommendations

- Long-term real-time gaging of the Dearborn Canal, Flat Creek (near the DNRC Flat Creek Canyon gage location or Highway 200) and the Dearborn River above the diversion would provide irrigators with valuable information about the amount of water diverted and consumed by the system. These data could be used to better manage the system to help reduce waste water and to run the system as efficiently as possible especially during the water short months of July, August, and September.
- The agencies and stakeholders should consider forming a working group of interested parties to achieve local watershed goals, including efficiently managing irrigation diversions and reducing the days when temperatures in the lower river exceed thresholds for aquatic life.

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Appendix A. GPS locations of DNRC Gages

Site Name	Site ID	Lat	Long
Upper Dearborn	DR-01	47.28076	-112.483
Middle Fork Dearborn	DR-03	47.22038	-112.244
Dearborn Hwy 200	DR-02	47.21943	-112.242
South Fork Dearborn	DR-04	47.16119	-112.219
Flat Creek Hwy 200	DR-06	47.30338	-112.122
Flat Creek Canyon	DR-07	47.2235	-112.059
Dearborn Mouth	DR-08	47.13118	-111.913

Appendix B DNRC Irrigated Land Delineation Method

Irrigated lands were delineated at a 1:6,000 scale in Arc GIS. DNRC personnel digitized lands by hand drawing a polygon around the border of the irrigated parcels. The imagery used during the delineation process included natural color (Red, Green and Blue) and near infrared imagery acquired from the United States Department of Agriculture's National Agriculture Imagery Program (NAIP). Digitized irrigated land polygons from the Water Resource Survey (WRS) and Final Lands Unit (FLU) data sets were referred to by DNRC personnel when determining irrigated lands. Some irrigated lands were field checked visually from publically accessible roads.

DNRC personnel used a classification scheme in the attributes table of the GIS program to characterize the irrigation in identified polygons. The attribute classification table included; Object ID, NAIP Imagery Year when irrigation appeared present, irrigation System Type, Crop Type, Supply Source Name, Certainty or Comments, and Acres.

Each identified irrigated land polygon was assigned a unique Object ID. The identified polygon was then examined in each of the three years of NAIP imagery (2005, 2009 and 2011), to estimate the presence and frequency of irrigation. Identified irrigated lands polygons were assigned irrigation present, irrigation absent or irrigation may be present depending on apparent presence of irrigation for each of the three NAIP imagery years. Lands determined to be sub-irrigated were assigned "irrigation absent".

Once the irrigated land polygon was determined to be irrigated an irrigation system type was assigned from a list of common irrigation types in Montana as follows: Center Pivot Sprinkler, Wheel Line Sprinkler, Other Sprinkler, Wild Flood, Flood Contour, Flood Other Improved (leveled). If the irrigated land polygon was identified to be sub-irrigated, a system type of sub-irrigated hay/pasture was assigned.

A crop type was then assigned to the irrigated lands polygon from a list of common Montana crop types. A cropland data layer from the USDA, National Agricultural Statistics Service for 2011 was utilized to help identify crop types during classification process. Crop types were assigned from the following list: alfalfa hay, grass hay, grain, irrigated pasture, pasture and none or other.

A supply source was assigned by drainage or if source supply data was available from WRS that data was utilized. Certainty of the irrigated lands and comments were added in the attribute table where appropriate.

The area of identified irrigated land polygons was quantified in Arc GIS to gain an estimate of the amount of irrigated and sub-irrigated lands in the Dearborn. Irrigation could also be sorted by source stream within the watershed.

Appendix C DNRC ET Remote Sensing Estimation Method

Estimating evapotranspiration (ET) using remote sensing techniques required Landsat 7 (USGS and NASA, 2007) imagery over the 2007 irrigation season. The resolution of Landsat 7 pixels are 30 square meters. Landsat scenes are unusable if the cloud cover is greater than 30%. Cloud cover in usable Landsat scenes is masked using products and protocols developed by the USGS. The cloud cover processed Landsat scenes were then downloaded into GIS for processing. In 2007 usable Landsat scenes for the Dearborn watershed were available for June 23, July 09, July 25, August 26 and September 11.

The DRNC remote sensing method requires the creation of a shortwave composite image using three of the Landsat Satellite Enhanced Thematic Mapper Plus band designations. Red (Band 3) is used to determine plant growth as low reflectance of this band indicates high plant growth. Near Infrared (Band 4) is used to determine plant growth as high reflectance of this band indicates high plant growth. The thermal Shortwave Infrared (Band 7) is used to identify hot and cool areas. Evaporation of water causes cooling, cool shortwave infrared values indicate high evaporation (high water use) and hot values indicate low water use and low evaporation.

A transpiration grid is created by subtracting the Red (band 3) from Near Infrared (Band 4). An evaporation grid is created using Shortwave Infrared (Band 7). The ranges of values for both grids are bounded to remove anomalous high and low values.

The values of the transpiration and evaporation grids are further bounded to reflect actual water use by selecting the hottest and coldest pixels within known irrigated lands. Hot and cold pixel selection is subjective and the decision is based color imagery and local agricultural knowledge.

Due to evaporative cooling, the coldest pixel in the transpiration grid represents the area of highest plant growth. The transpiration reference is created by selecting the coldest transpiration pixel value. The hottest pixel of the transpiration grid represents no growth and this value is also identified. The hottest pixel in the evaporation grid represents the area with the least evaporation and lowest water use. The evaporation reference value is created by selecting the hottest evaporation pixel value. The coldest pixel in the evaporation grid indicates the most evaporation and highest water use.

The transpiration and evaporation grids and reference values are combined and averaged to create an evapotranspiration (ET) grid and (ET) reference value for each pixel.

The Great Falls or the Helena Valley stations AgiMet weather stations were used to compute ET values. These are the closest AgriMet stations to the Dearborn watershed and most closely represent conditions found in the Dearborn. Over the growing season the AgriMet stations compute theoretical reference ET values for Alfalfa Mix based on local weather conditions. AgriMet theoretical values were averaged for several days preceding and proceeding the date of the Landsat scene. Averaging the ET values helps mitigate anomalous values that could occur due to crop cutting or cloud cover.

The DNRC irrigated lands polygons were overlaid on each of the five abovementioned Landsat scenes. The pixel values within the identified field polygons were averaged for each individual scene. The field pixel value was then compared to the highest ET value and the pixel value was converted to a reference percent. The field reference percent was then multiplied by the averaged AgriMet theoretical ET that date to determine actual ET.

The gaps between the Landsat scene dates were filled by multiplying the most recent field reference ET percent (determined by each Landsat scene) by the daily AgriMet theoretical alfalfa mix value.

Precipitation measured at the AgiMet station from January 1st to April 1st was used to estimated soil moisture (carry over) conditions and mimic plant use of existing soil moisture in the spring. Precipitation over the irrigation season was considered to be effective if the 24 hour precipitation was less than 0.5 inches. If the 24 precipitation was greater than 0.5 inches it was estimated that the additional precipitation would runoff via surface flow and only 0.5 inches was used. Precipitation (effective precipitation) was subtracted from the calculated ET for that day as: plant growth likely utilized natural precipitation, irrigation did not occur due to precipitation or precipitation added additional moisture to the soil.

ET over the irrigation season was summed up and aggregated at the drainage scale.

Appendix D: Streambed Temperature Monitoring

Surface water and groundwater have distinct temperature signals during the summer months. The temperature of surface water changes with the warming and cooling of ambient air. Groundwater tends to have a stable cool temperature signal which reflects the average annual air temperature. Observation of these temperature signals in the streambed at and at shallow depths below the surface gives insight into the near surface groundwater and surface water interactions occurring near the gage. Surface and groundwater interactions are dynamic spatially and temporally and these interactions are likely influenced by changing flow conditions on the river. This section uses streambed and surface water temperature comparisons to provide some insights on how water might be exchanged between the streams and the adjoining shallow aquifer systems. Further study would be required to quantify how the Dearborn River is interacting with the aquifer system.

Streambed temperature monitoring was conducted at the Upper Dearborn, Dearborn Highway 200, Dearborn Mouth, Middle Fork Dearborn, South Fork Dearborn, Flat Creek Highway 200 and Flat Creek Canyon sites in 2007 and 2008. Instrumentation was lost at the Upper Dearborn and Dearborn Highway 200 sites during the flooding event in 2008. Streambed sensors were not replaced.

Data is presented to provide information about near surface groundwater and surface water interactions at the gaging sites. Streambed temperature data has been summarized as daily maximums and minimums for simplicity during graphing.

Streambed temperature monitoring at the Upper Dearborn site is graphed in Figure 1. The Upper Dearborn site represents the coolest monitoring site on the Dearborn River. The daily signal for 2007 indicates that daily surface water temperatures are heavily influenced by changes in ambient air temperature as indicated by the large difference in temperature over the give day. In general, diurnal temperature signals are observed at all three sensors depths suggesting that groundwater is not upwelling at this site.

Early in the season prior to runoff the diurnal temperatures were observed at 1.5 and 3.5 ft appear to be muted compared to the surface water suggesting that some influence from ground water may be present at this time. The observation of a strong diurnal temperature signals (July, August and September) at the deepest sensor (3.5 ft) suggests that surface water may be seeping through the streambed to the groundwater.

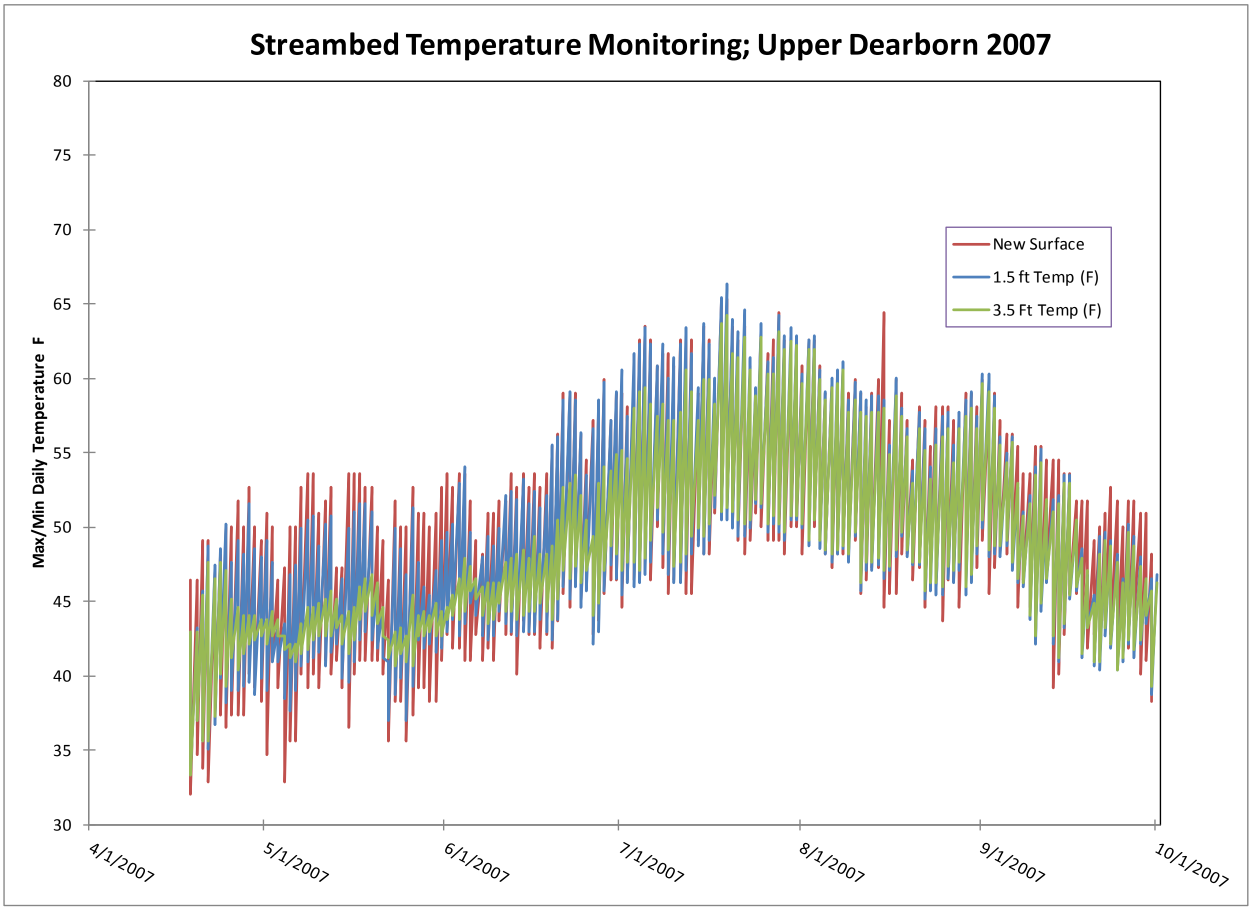

Figure 1: Streambed temperature monitoring at the Upper Dearborn site in 2007. Instrumentation was lost during flooding in 2008.

Streambed temperature monitoring at the Dearborn Highway 200 site for 2007 is graphed in Figure 2. Temperature data at the Highway 200 site indicates that temperatures cool with depth and that diurnal changes in ambient air temperature heavily influence the surface and shallow, 1.5 ft streambed temperatures. The signal at 3.9 ft is responding to seasonal changes in temperature, however diurnal influences are muted.

A dramatic change in the temperature signal is observed in early August 2007. This change is occurring when flows in the river are approaching the lowest recorded during the study.

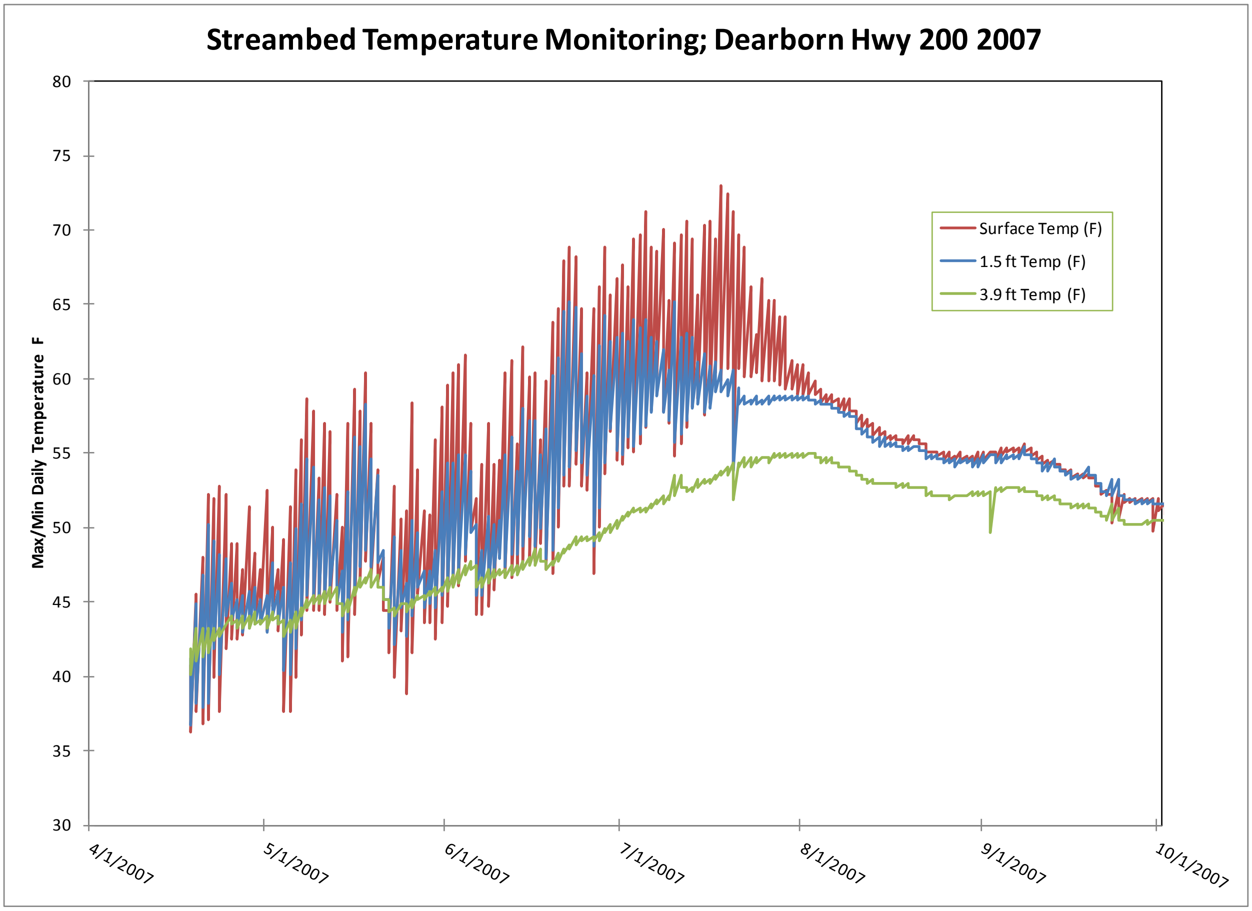

Figure 2: Streambed temperature monitoring at the Dearborn Highway 200 site for 2007. Instrumentation was lost during flooding in 2008.

Streambed temperature monitoring at the Dearborn Mouth site for 2007 and 2008 is graphed in Figure 3. Diurnal changes in ambient air temperature heavily influenced surface water and shallow, 1.5 ft streambed temperatures in May and June. The temperature signal at 3.9 ft is responding to seasonal changes in temperature, however diurnal influences are muted during the entire 2007 monitoring season. A shift in the temperature signal is observed starting in July of 2007 when the surface and shallow streambed (1.5 ft) and deep streambed (3.9 ft) temperatures became muted. The cause of this change is unknown.

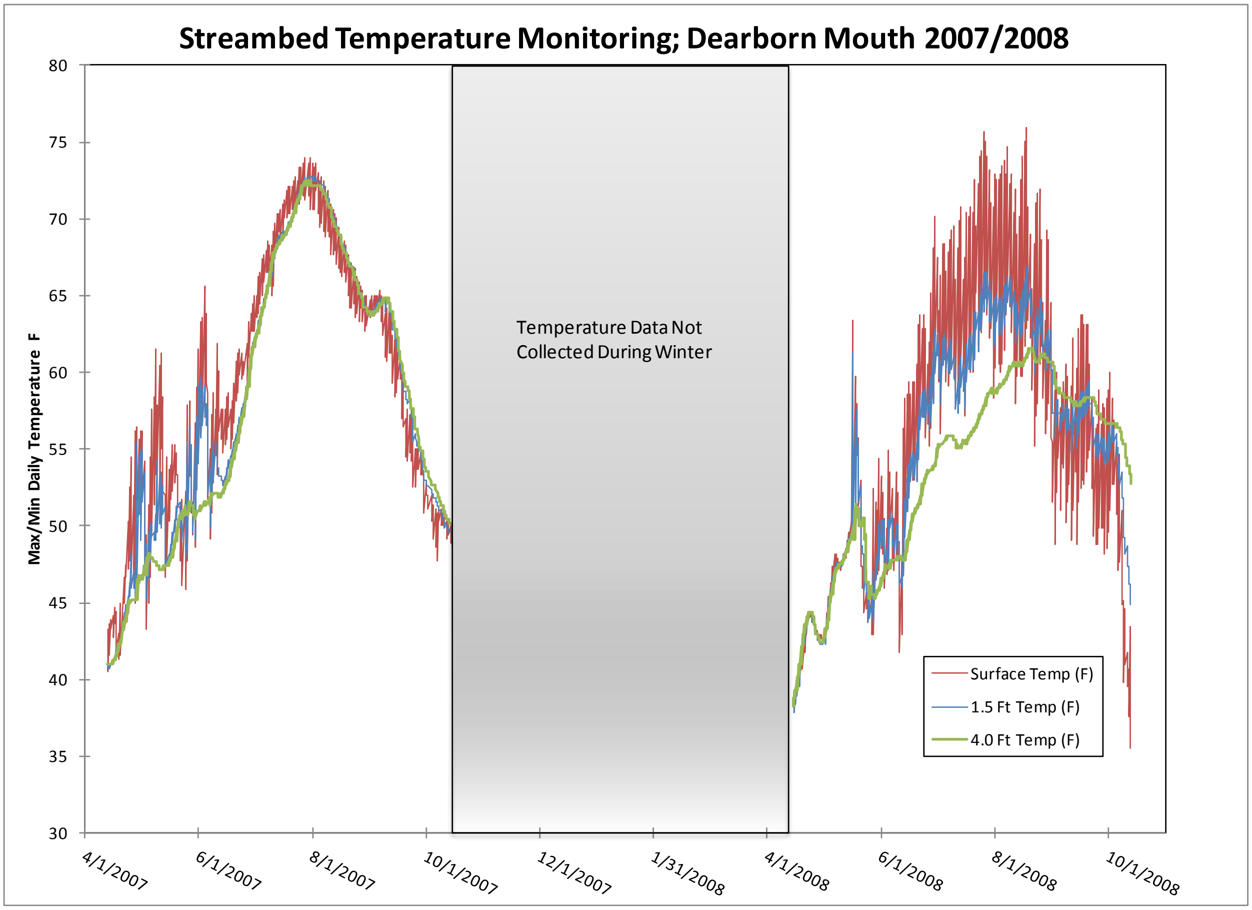

Figure 3: Streambed temperature monitoring at the Dearborn Mouth site for 2007 and 2008.

In the spring of 2008, the temperature signals of all three sensors are nearly identical. This temperature pattern is not observed at the other Dearborn sites. The temperature signal of the surface and shallow streambed shifts in June of 2008, diurnal changes in temperature are observed again. The temperature data collected at the Dearborn Mouth site suggests that the temperature regime is dynamic. Due to the limitations of this study, further information is required to verify interactions.

Streambed temperature monitoring at the Middle Fork Dearborn site for 2007 and 2008 is graphed in Figure 4. Temperature data collected on the Middle Fork for 2007 indicates that diurnal changes in ambient air temperature heavily influence the surface and shallow streambed (1.5 ft) temperatures for the entire season. The surface and shallow streambed temperatures were observed to be nearly identical. The muted temperature signal from the deeper streambed (3.9 ft) closely follows that of the surface and shallow streambed.
The temperature signal in 2008 starts out mimicking the pattern observed in 2007. In June of 2008, the shallow streambed temperature becomes muted and the deeper streambed temperature becomes more muted than what was observed in 2007.

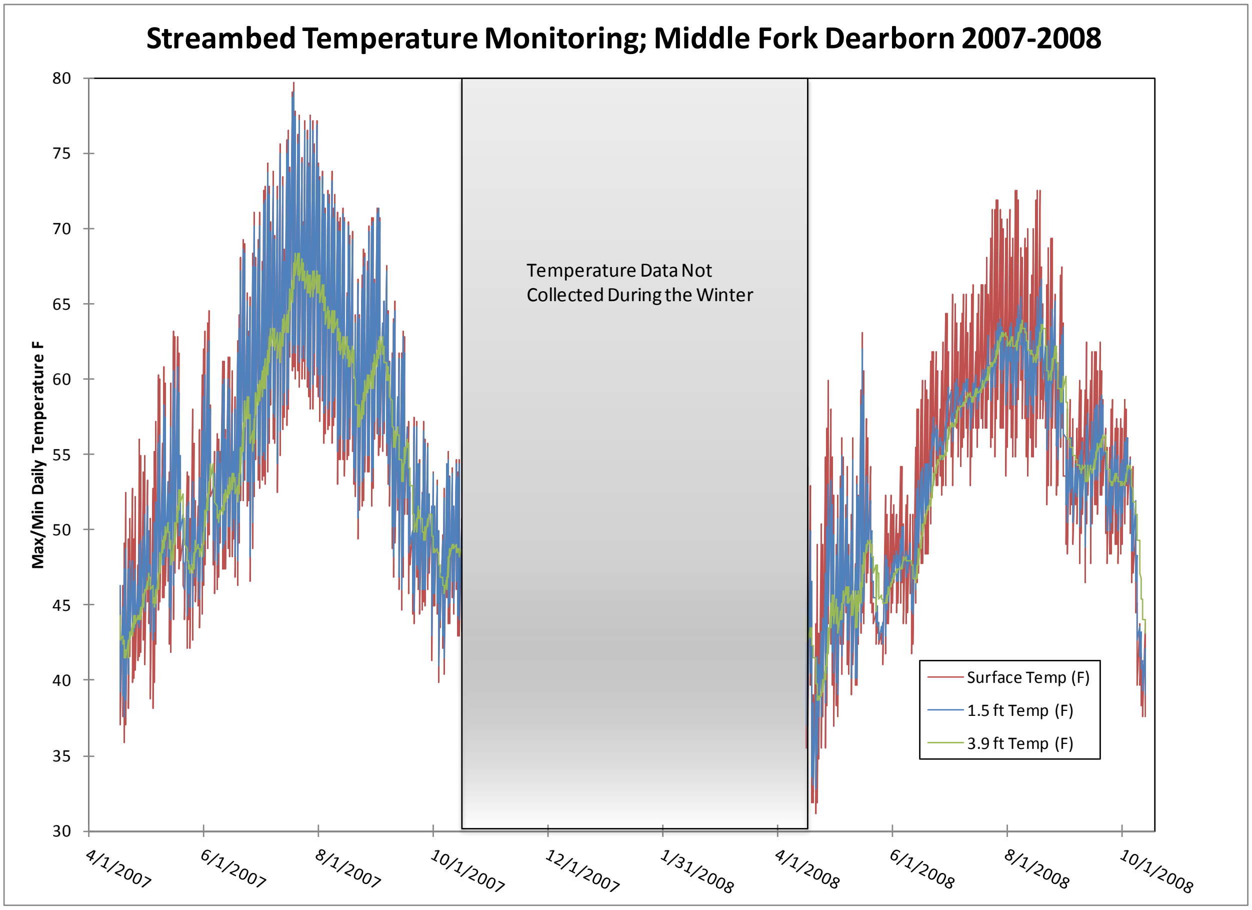

Figure 4: Streambed temperature monitoring at the Middle Fork of the Dearborn site in 2007 and 2008.

Streambed temperature monitoring at the South Fork of the Dearborn site for 2007 and 2008 is graphed in Figure 5. The surface water, shallow streambed (1.5 ft) and deeper streambed (3.5 ft) indicated a cool, muted signal. Diurnal influences on temperatures were minimal during 2007. A shift in the surface temperature pattern is observed in 2008. The influence of diurnal changes in ambient air temperatures are observed throughout the entire monitoring season. The shallow (1.5 ft) and deeper streambed (3.5 ft) continue to indicate a cool and muted signal in 2008.

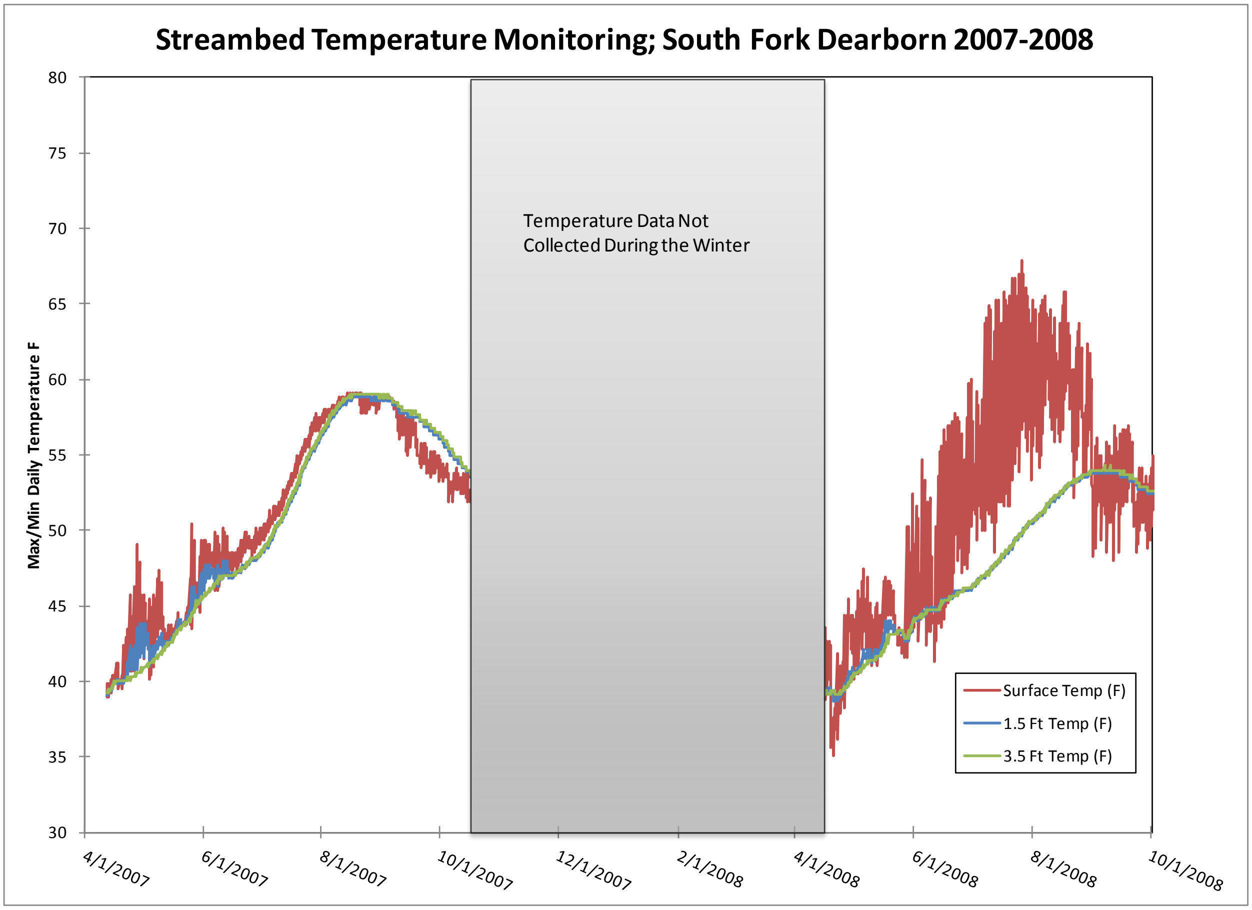

Figure 5: Streambed temperature monitoring at the South Fork of the Dearborn site in 2007 and 2008.

The cause for a shift in the surface water temperatures is unclear. However, water temperature at the South Fork Dearborn site in 2007 and 2008 appears to be influenced by the presence of groundwater contributions.

Streambed temperature monitoring at the Flat Creek Highway 200 site for 2007 and 2008 is graphed in Figure 6. Streambed temperatures observed at the Flat Creek Canyon site closely match the pattern observed on the Middle Fork of the Dearborn. In 2007, the surface and shallow streambed (1.5 ft) temperatures are nearly identical. The deeper streambed (4 ft) temperature, although muted, closely follows that of the surface temperature. A slight change in the temperature pattern is observed in 2008 with the shallow and deeper streambed becoming more muted compared to 2007.

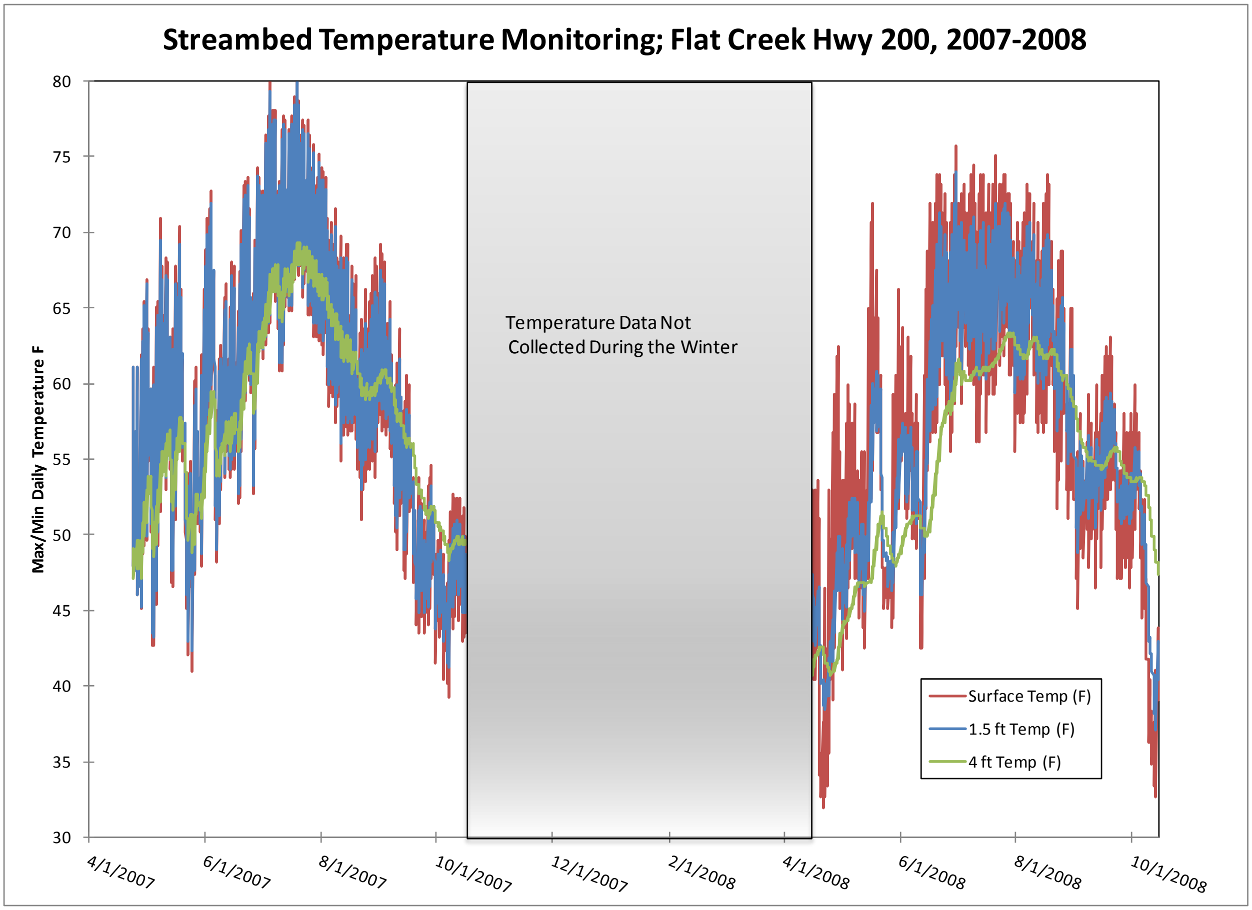

Figure 6: Streambed temperature monitoring on Flat Creek at Highway 200 for 2007 and 2008.

Streambed temperature monitoring at the Flat Creek Canyon site for 2007 and 2008 is graphed in Figure 7. The temperature signals observed at the Flat Creek Canyon site indicate that diurnal changes in ambient air temperature influenced the surface water temperature in 2007 and 2008. The surface temperature signal appears to be slightly muted in 2007. Streambed temperatures, both shallow (1.5 ft) and deep (3.0 ft) indicate a cool, muted signal that follows seasonal trends. The surface and shallow streambed temperatures in 2008 appear to be influenced more heavily by the ambient air temperature. Changes in the temperature signal in 2008 add uncertainty to any conclusions from this data and future study would be required to properly characterize surface water and groundwater interactions at this site.

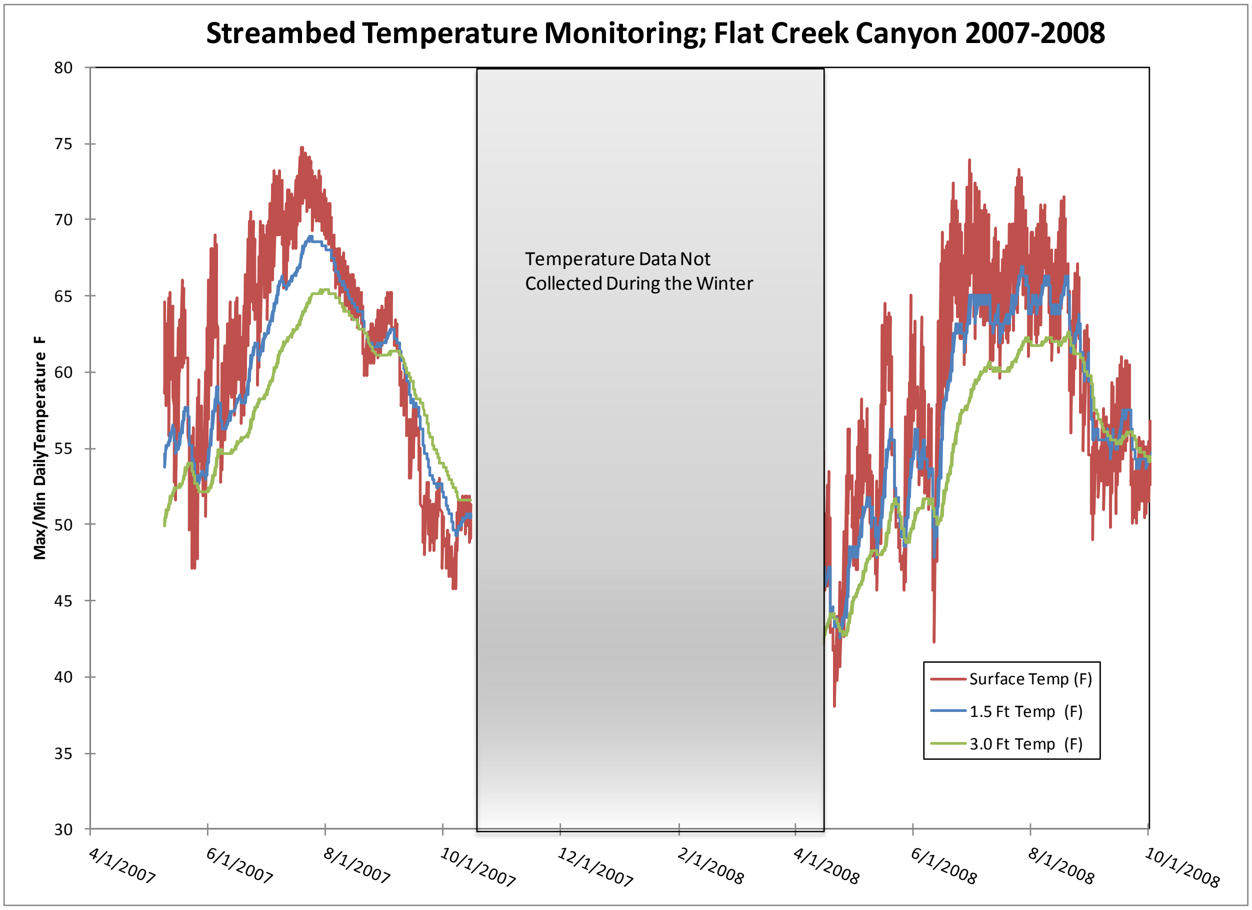

Figure 7: Streambed temperature monitoring at the Flat Creek Canyon site in 2007 and 2008.

Streambed temperature monitoring conducted in 2007 and 2008 captured two very different water years. Flows in 2007 were in the lower quartile and flows in 2008 were slightly above normal.