RECLAMATION

Managing Water in the West

Hydraulic Laboratory Technical Memorandum PAP-1127

Recommended Flow Measurement and Remote Monitoring Upgrades for Delivery System Operations

Yuma Project Reservation Division
Lower Colorado Region

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

July 2016

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Acronyms and Abbreviations

BWD	Bard Water District
CFM	Continuous Flow Meter
CHO	Constant Head Orifice
CSV	Comma-Separated Values
DRU	Ditchrider Unit
PC	Personal Computer
Reclamation	Bureau of Reclamation
RMC	Reservation Main Canal
SCADA	Supervisory Control and Data Acquisition
TM	Technical Memorandum
TSC	Technical Service Center
UHF	Ultra-High Frequency
U.S.	United States
USGS	United States Geological Survey
WCFSP	Water Conservation Field Services Program
YAO	Yuma Area Office
YCWUA	Yuma County Water Users Association
YMC	Yuma Main Canal

Introduction

The Reservation Division of the Yuma Project is located in extreme southeastern California directly north of Yuma, Arizona. This investigation is part of a larger study looking at the current condition of the water delivery network with the objective of identifying conveyance system bottlenecks along with potential systemic and operational improvements that enhance water delivery efficiency. The objective of this investigation is to identify key sites in the Reservation Division water delivery system where additional flow measurement capability can be of greatest value and from where real-time ability to remotely access flow information and remotely adjust control structures can be cost-effective for improving water delivery operations efficiency.

A flow monitoring demonstration project – funded through the Water Conservation Field Services Program (WCFSP) of the Bureau of Reclamation's Yuma Area Office (YAO) – was undertaken concurrently with this investigation. The field demonstration project served to verify the functionality and suitability of proposed systems and site configurations that are being recommended as part of this study.

Background

The Reservation Division of the Yuma Project consists of tribally-owned lands in the Indian Unit plus privately-owned lands in the Bard Unit. In addition, water is delivered through the Reservation Division conveyance system to multiple "Tribal Ranch" areas along the perimeter of these two Units that were not irrigated as part of the original Yuma Project.

The bulk of the lands in the Indian Unit lie west of the north-south oriented Baseline Road. Additional Indian Unit parcels lie along the northern fringe of the Bard Unit. Under current operations, the Bard Water District (BWD) oversees water delivery operations in the Indian and Bard Units as well as deliveries to multiple "Tribal Ranch" areas that receive Colorado River water through the Reservation Division water distribution system.

Figure 1 is a map of the Reservation Division. Water conveyed through the Reservation Division canal network is diverted from the All-American Canal which runs along the northern edge of the Reservation Division lands. There are five turnouts from the All-American directly into Reservation Division canals. These include the headings of the Ypsilanti, the Pontiac, the Yaqui, the Titsink and the Reservation Main canals.

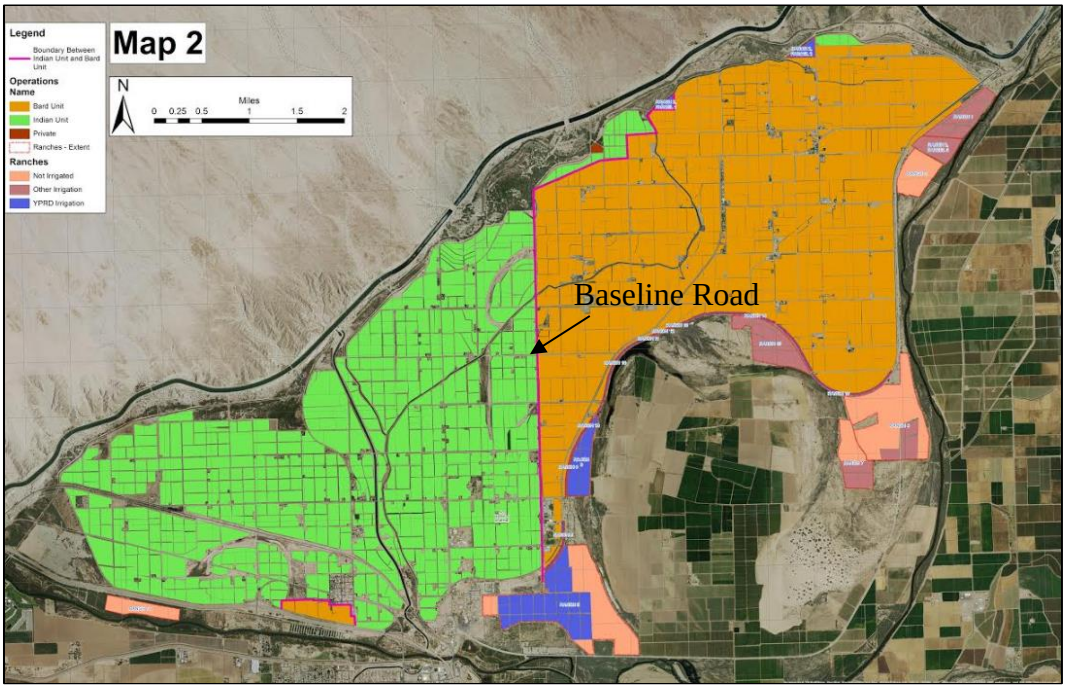

Figure 1.—Map of the Reservation Division of the Yuma Project.

In addition, water is diverted from the All-American canal into the Yuma Main Canal (YMC), which passes through Indian Unit lands. Along the reach of the YMC that passes through the Indian Unit, there are fourteen active small turnouts and two sizeable lateral turnouts.

Within the Reservation Division there are multiple canals and laterals that deliver water to lands in both the Indian and Bard Units. From this brief overview of the water delivery network in the Reservation Division, a high degree of complexity in managing water deliveries can readily be appreciated.

Scope of Study

Tasks that were undertaken for this study included multiple site visits to physically inspect existing delivery system aspects and interact with BWD staff to become familiar with the existing physical system components as well as the operational methodologies being employed. Additional resources utilized include existing Project maps and Google Earth™ imagery to help understand the dynamics of delivery system operations and to develop a sense of how integration of electronic monitoring and control technologies might impact delivery system operations. Flow monitoring and the associated required flow measurement capabilities were the focus of this study. Potential for addition of automated and/or remote operation of flow control structures was considered but not included in the recommendations developed in this effort.

Sites to be included for recommendation as initial monitoring network sites fall within one of the following groupings:

- Points of inflow
- Major spill locations
- Key locations along major canals
- Lateral headings
- Administrative boundary crossings
- Yuma Main Turnouts

For recommended sites, installation cost estimates have been developed for electronic control and communications systems. At recommended sites where no current flow measurement equipment/structures are present, a suggested device/structure is identified along with an estimated installed cost.

Recommended Monitoring Project Field Sites

Points of Inflow

All of the irrigation water applied within the Reservation Division along with all irrigation water delivered through the Reservation Division conveyance system to adjacent "Tribal Ranches" is diverted from the All-American Canal. Diversions from the All-American as shown in Figure 2, beginning at the furthest upstream site include:

- Reservation Main Canal (RMC)
- Titsink Canal (Titsink)
- Yaqui Canal (Yaqui)
- Pontiac Canal (Pontiac)
- Yuma Main Canal (YMC)
- Ypsilanti Canal (Ypsilanti)

The bulk of the water carried in the YMC is conveyed across lands in the Indian Unit to an inverted siphon under the Colorado River. From the inverted siphon, water in the YMC is delivered Yuma County Water Users Association (YCWUA) fields lying in the Colorado River valley bottom lands between Yuma and the Mexico Border. The YMC is operated by the YCWUA. The YMC flows of interest for this investigation are not the inflows from the All-American but rather flows turned out from the YMC as it passes through the Indian Unit before reaching the inverted siphon at the Colorado River. These turnouts from the YMC are considered in a later section of this report.

Each of these inflow locations – except for the Titsink – is monitored by the USGS. Data generated by the USGS facilities is available from the USGS website however availability of this data is delayed by a sufficient time lag to limit the usefulness of the information for real-time canal operation needs. The USGS data is typically relied on for diversion records.

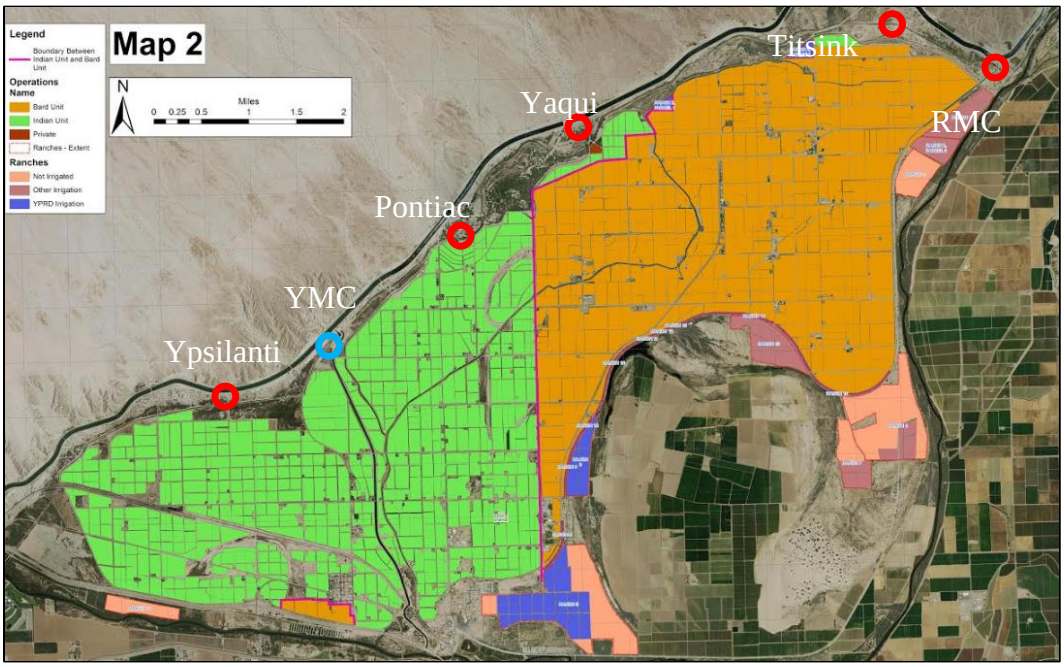

Figure 2.—Diversion points along the All-American Canal.

RMC

The RMC turnout is the largest capacity of the five turnout sites that deliver exclusively to lands in the Reservation Division and adjacent ranches. The turnout gate is motorized for local operation. There is no flow measurement device or structure at this turnout. USGS monitoring of this site appears to be based on electronically sensed gate opening. Figure 3 is a Google Earth™ image of the RMC turnout.

Figure 3.—Suggested measurement location for RMC turnout from the All-American.

There is no location in the Reservation Division that would be of greater importance for accurate and reliable flow measurement. There are suitable conditions for installation of a long-throated flume in the earthen canal. A flume could be installed downstream from the 11th Street bridge (red circle in Figure 3) to provide a sufficient length of straight canal approaching the flume location along with more than ample distance from the nearest downstream structure (the check at the Acoma heading).

An alternative consideration would be to equip the check in the RMC that is adjacent to the Acoma turnout for gate-flow measurement. A flume could provide greater measurement accuracy, however the accuracy from gate-flow measurement may be suitable for daily operational needs. [The Acoma is already equipped with a flume so the combination of flow entering the Acoma plus flow passing the check would capture the full RMC turnout from the All-American]

Titsink

The Titsink handles the smallest volume of flow among Reservation Division turnouts from the All-American. The gate on the All-American is manually operated. There is no flow measurement device/structure at this site. Suitable conditions exist for installation of a long-throated flume in the earthen canal at this site. Figure 4 shows the upper reach of the Titsink Canal.

Figure 4.—Heading of the Titsink Canal.

Yaqui

The Yaqui turnout from the All-American has a manually operated gate. Flow is measured passing through a flume that is a USGS monitored site. Figures 5 and 6 show the Yaqui gate and flume respectively.

Figure 5.—Yaqui gate.

Figure 6.—Yaqui flume.

Pontiac

The Pontiac turnout from the All-American is quite similar to the Yaqui. The Pontiac has a manually operated gate and flow is measured as it passes through a flume that is quite similar to the Yaqui flume which is also a USGS monitored

site. Both sites appear to be of similar capacity. Figures 7 and 8 show the Pontiac gate and flume respectively.

Figure 7.—Pontiac gate.

Figure 8.—Pontiac flume.

Ypsilanti

The Ypsilanti turnout from the All-American is the furthest downstream turnout from the All-American that serves the Reservation Division. Flow from the Ypsilanti gate is conveyed through a pipeline approximately 1,450 feet long. At the pipe outlet flow enters a stilling basin before passing over a Cipolletti weir. The weir is a USGS monitored site.

In 2001 the Ypsilanti was set up as a demonstration site for a prototype automated gate control system. At that time the gate was motorized and gate controls were linked to the weir site by a cable buried along the pipeline path. Currently the gate is being operated remotely from the flume site using a toggle switch control. Figure 9 is a Google Earth™ image showing the Ypsilanti gate and weir sites.

Figure 9.—Ypsilanti sites.

Major Spill Locations

Three spill locations were identified that are recommended as monitoring sites. These sites are:

- Spill above the RMC – Mohave Split
- Cocopah Wasteway near the end of the Cocopah Canal
- Tonawanda spill into Drain #11 at Arnold Road

Figure 10 shows the respective locations of these spills.

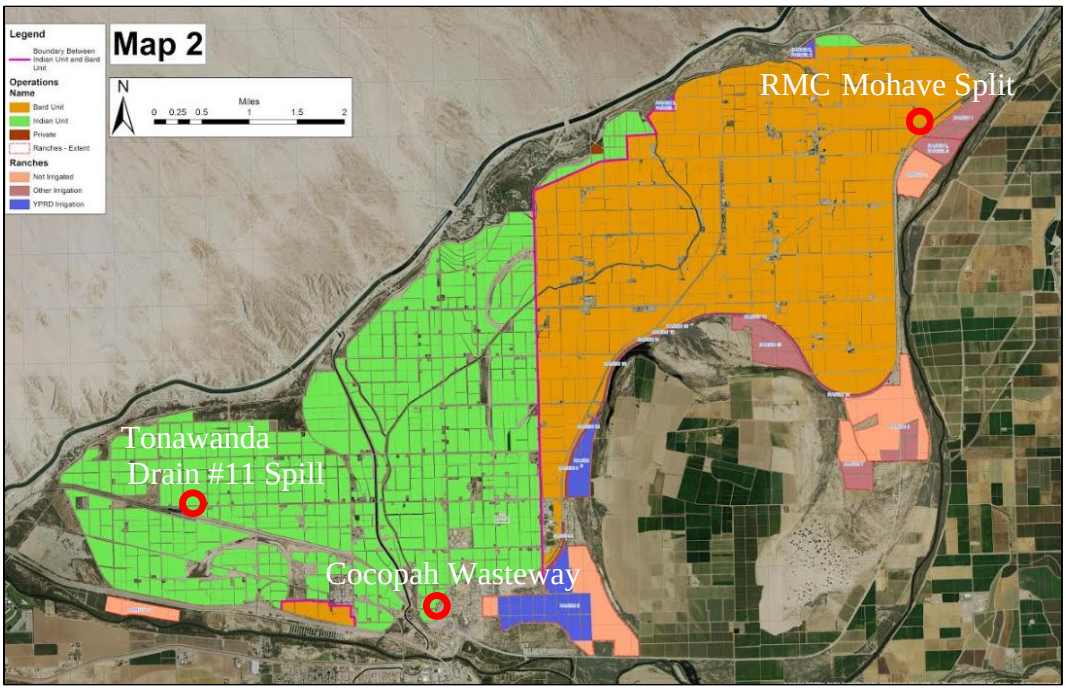

Figure 10.—Spill sites recommended as monitoring sites.

RMC – Mohave Split

A spill weir is located along the right side of the RMC immediately upstream from the location where the Mohave splits from the RMC. Water spilling over the weir continues on down the RMC. The spill flow rate would be calculated based on the measured upstream water level relative to the elevation of the spill weir. Figure 11 shows the RMC – Mohave spill weir.

Figure 11.—Spill at the RMC – Mohave Split.

Cocopah Wasteway

Near the tail end of the Cocopah Canal, excess flows are routed through the Cocopah Wasteway into Drain #4. The structure at the head of the Cocopah Wasteway is set up with a stilling well for measuring water level. As presently configured, the structure is not set up to function as a standard flow measurement structure. With limited modification effort it could be reconfigured as a suppressed rectangular sharp crested weir to monitor spill flows. Figure 12 shows this structure.

Figure 12.—Structure at the head of the Cocopah Wasteway.

Tonawanda Spill Into Drain #11

Excess flows in the Tonawanda Canal may be spilled into Drain #11 at a structure at the south edge of Arnold Road. Spilled flow at this site is controlled by a vertical slide gate. By equipping this gate to monitor vertical gate position and by monitoring water levels upstream and downstream of the gate, spill at this site could be measured using orifice flow calculations. Figure 13 is a photo of the site.

Figure 13.—Tonawanda Spill into Drain #11.

Key Locations Along Major Canals

Six locations are included in sites recommended as monitoring sites along major canals in the delivery system. These sites include:

- The Ypsilanti East – Ypsilanti West split
- The Pequod – Navajo junction
- The Cocopah flume below the Cocopah #3 turnout
- The RMC – Moqui split
- The RMC – Apache split
- The RMC – Mohave split

Locations of these sites are shown in Figure 14.

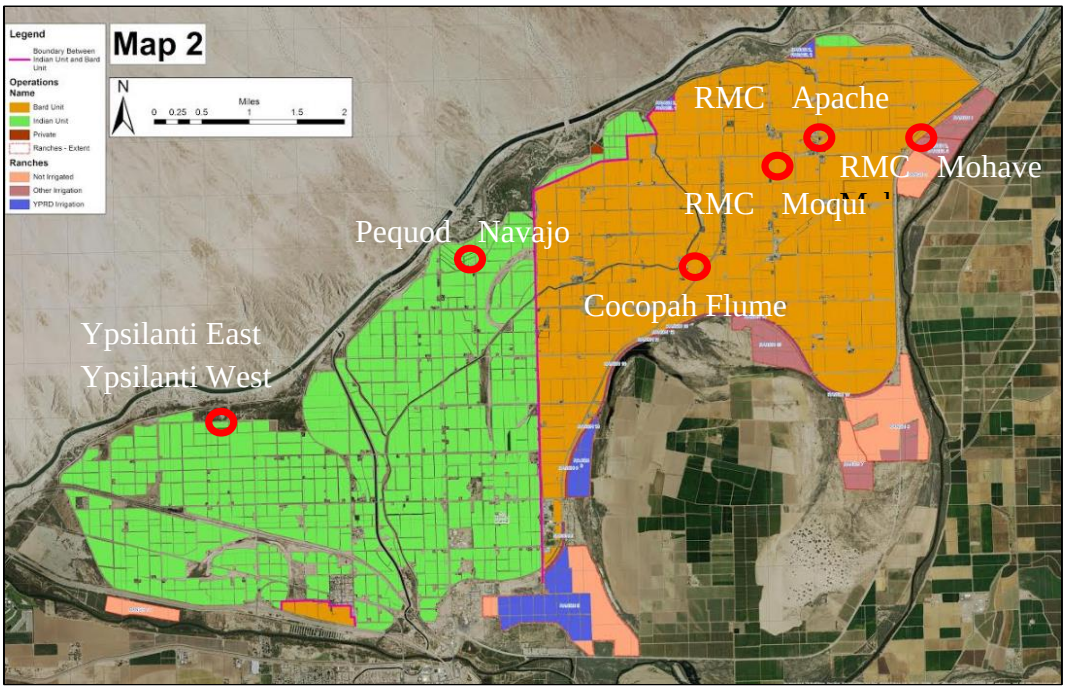

Figure 14.—Key locations along major canals.

Ypsilanti East – Ypsilanti West Split

The Ypsilanti East and Ypsilanti West canals proceed in opposite directions immediately downstream from the Cipolletti weir at the exit of the piped section at the head of the Ypsilanti. Ramp-type long-throated flumes are installed in both the Ypsilanti East and the Ypsilanti West. Figures 15 and 16 show these flumes.

Figure 15.—Ypsilanti East flume.

Figure 16.—Ypsilanti West flume.

Pequod – Navajo Junction

The Pequod and Navajo canals are segments of the delivery system fed by the Pontiac diversion from the All-American. A short distance below the split of these two canals flow is measured by ramp-type long-throated flumes in each canal. Given the proximity of the two flumes both could be monitored by a single radio/control station. Figure 17 is a Google Earth™ satellite view showing both of these flumes.

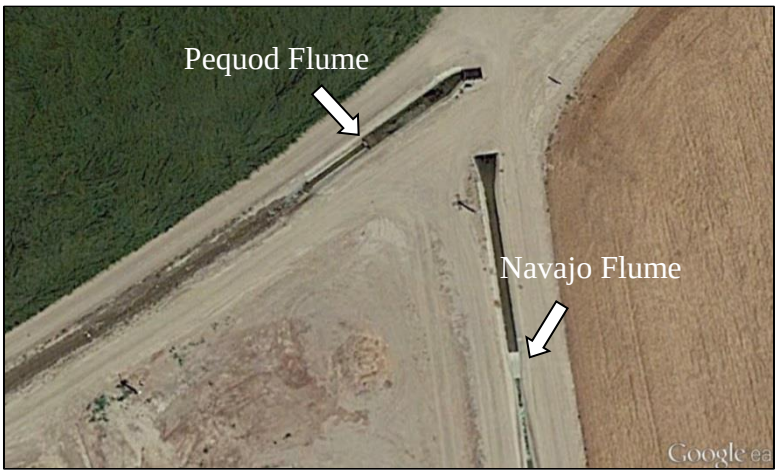

Figure 17.—Aerial image showing the Pequod and Navajo flumes.

Cocopah Flume

The Cocopah flume is a "mid-system" flow measurement point along one of the primary canals in the Reservation Division water delivery system. This ramp-type long-throated flume was installed as part of a major system upgrade project completed in 2008. BWD management has stated that since the flume was installed draining the canal reach above the flume in order to perform maintenance tasks has become an operational challenge. Drain pipes that were installed along the canal invert under the flume have insufficient capacity to allow upstream water trapped below the flume crest to drain in a timely manner. BWD has expressed interest in replacing the current ramp-type long-throated flume with a laterally contracted flume. Figure 18 is a Google Earth™ "Street View" image showing the flume site.

Figure 18.—Cocopah flume.

RMC – Moqui Split

Flows into the Moqui and the Moqui #1 from the RMC are controlled by separate vertical slide gates. The Moqui gate is located approximately 45 feet upstream of a check in the RMC. The Moqui #1 gate is located approximately 25 feet further upstream. Both the Moqui and the Moqui #1 are unlined earthen canals.

There are no existing flow measurement structures in the Moqui, the Moqui #1 or the RMC at this location. It may be feasible to equip the turnout gates as well the check gates to make gate flow measurements in three directions from this location with a single radio/control installation. Figure 19 is a Google Earth™ satellite view of the site.

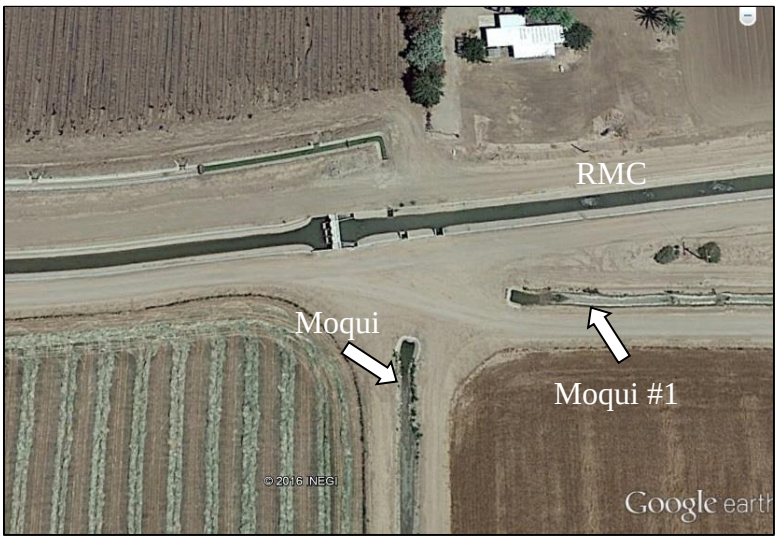

Figure 19.—Moqui and Moqui #1 turnouts from the RMC.

RMC – Apache Split

The upper reach of the Apache as it takes off from the RMC is a concrete lined canal. There is no existing flow measurement structure in this canal reach. The Apache begins in a gradual curve that ends approximately 275 feet from the RMC. It would be cost effective to install a long-throated flume to measure flow entering the Apache. A hydraulically suitable location for a flume would be approximately 65 feet (~ 40 hydraulic radii) downstream from the end of the curve. Figure 20 is a Google Earth™ image of the RMC turnout to the Apache.

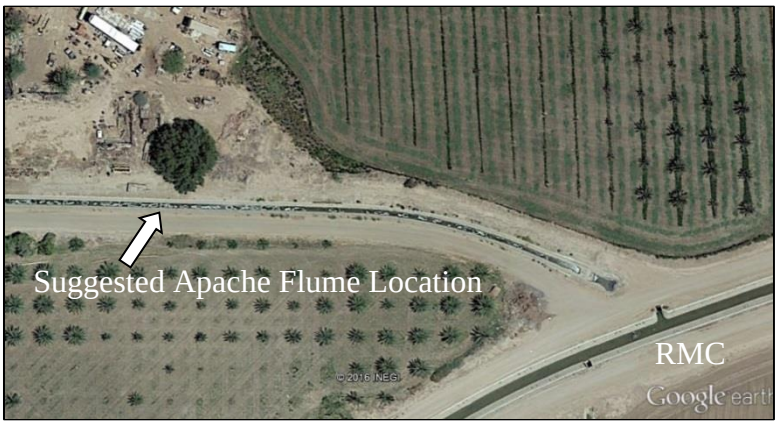

Figure 20.—RMC turnout into the Apache.

RMC – Mohave Split

The Mohave branches off of the RMC at a location commonly referred to as "Five Gates". At this site water may flow from the upper reach of the RMC through one of two box culverts. Water passing through the right culvert proceeds down the RMC. Water passing through the left culvert enters the Mohave.
Flow proceeding down the RMC is controlled by three side-by-side vertical slide gates at the right culvert entrance. Flow entering the Mohave is controlled by two vertical slide gates installed in the bays of a check structure located approximately 20 feet downstream from the exit of the left culvert. The site is commonly referred to as "Five Gates" due to the total number of gates in the two canals. Five Gates is also the location of the previously discussed spill at the RMC – Mohave Split. Figure 21 is a Google Earth ™ image of the "Five Gates" site.

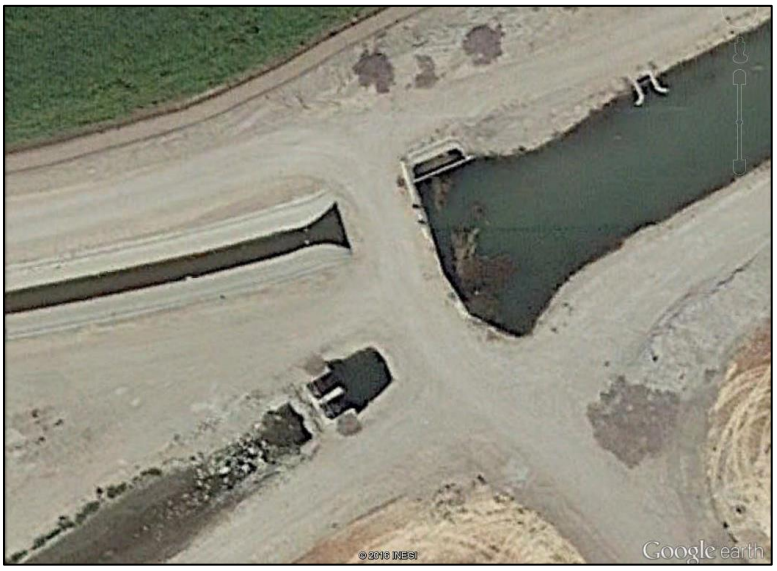

Figure 21.—"Five Gates," RMC-Mohave Split

Moving downstream from the Five Gates site, the RMC is concrete lined. The Mohave is unlined. There is a strong likelihood that at some point in time the capability to remotely operate gates controlling flow into each of the canals will be desired. For that reason it is recommended that two radio/control stations be installed – at locations adjacent to the flow control gates for each canal. Flow measurement capability for each canal could be accomplished by equipping the gates for the respective canals for gate flow measurement. The radio/control unit installed for the RMC could also monitor spill at the site. Figures 22 and 23 show the Mohave and RMC flow control gates respectively.

Figure 22.—Mohave flow control gates.

Figure 23.—RMC gates and spill weir.

Lateral Headings

Thirteen lateral heading locations are being recommended to be set up as monitoring network sites. These include:

- Tonawanda
- Comanche
- Walapai
- Pueblo
- Pima
- Papago
- Paiute
- Maricopa
- Klamath
- Kiawa
- Hopi
- Bannock
- Acoma

Locations of these canal headings are shown on Figure 24.

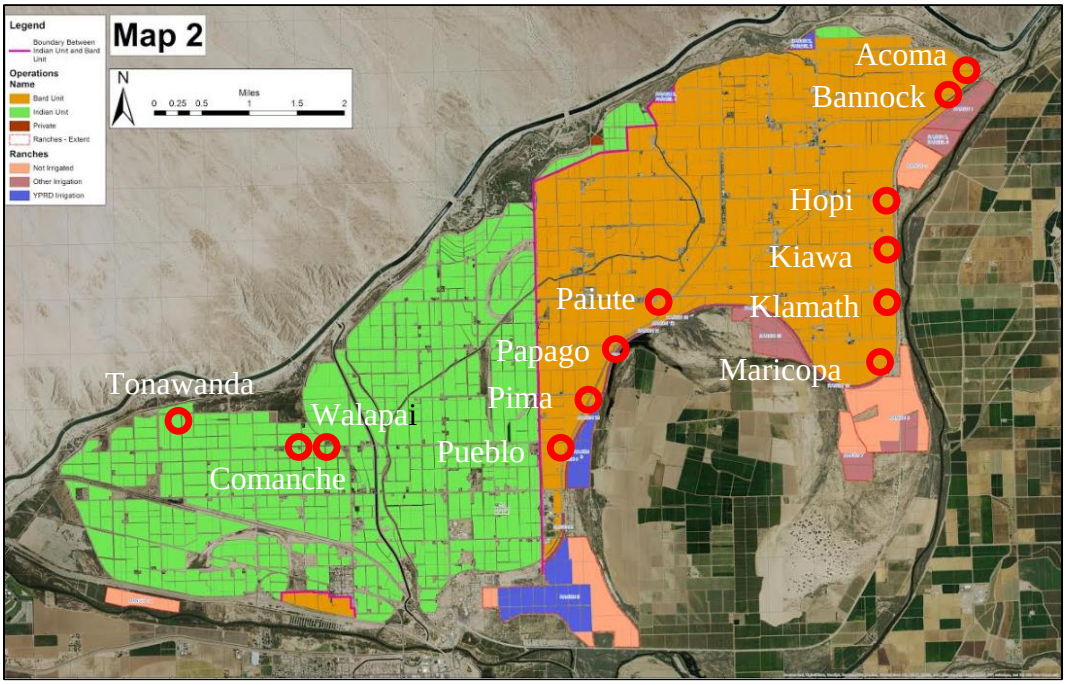

Figure 24.—Lateral headings recommended as monitoring sites.

Tonawanda

The Tonawanda branches off from the Ypsilanti West. A laterally-contracted long-throated flume which was installed at the site in 2013 was not located a sufficient distance downstream from the turnout from the Ypsilanti West for appropriate hydraulic flow conditions to develop prior to entering the flume. Planning is underway to relocate the flume approximately 75 feet (~ 40 hydraulic radii) downstream from the Ypsilanti West turnout to ensure suitable approach flow conditions entering the flume. Figure 25 shows the flume that will be replaced.

Figure 25.—"To be relocated" Tonawanda flume.

Comanche

The Comanche lateral branches off from the Ypsilanti East canal. A check in the Ypsilanti East at the site controls the flow rate proceeding downstream. The gate at the head of the Comanche is configured with a spill weir to the left of the gate. Excess flow at the site passes over the spill weir and proceeds down the Comanche. Flow proceeding down the Comanche is measured by a ramp flume located approximately 30 feet downstream from the gate. A monitoring station at this site would be set up to monitor flow over the weir. The check gate in the Ypsilanti East could also be equipped for gate flow measurement to be monitored by the same radio/control station. Figure 26 shows the Comanche heading.

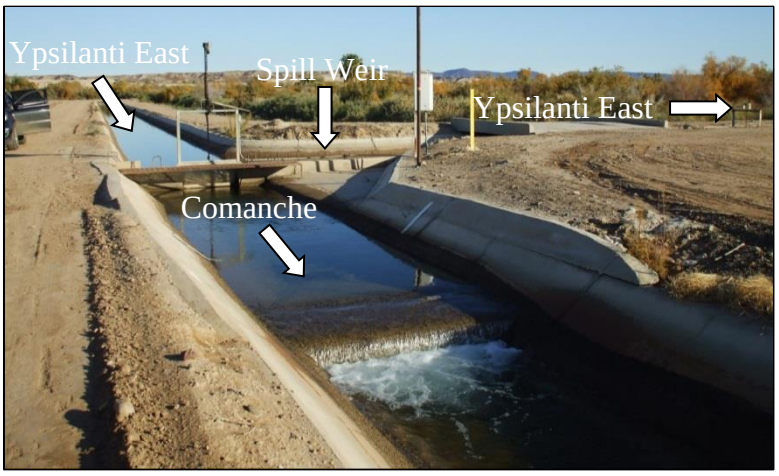

Figure 26.—Comanche flume and turnout from the Ypsilanti East.

Walapai

The Walapai is also fed by the Ypsilanti East. The Walapai is an unlined earthen canal. There is no existing flow measurement structure at the head of the Walapai. Figure 27 is a Google Earth™ image showing the upper reach of the Walapai with a suggested flume location approximately 52 feet (~ 40 hydraulic radii) downstream from the culvert outlet at the canal heading.

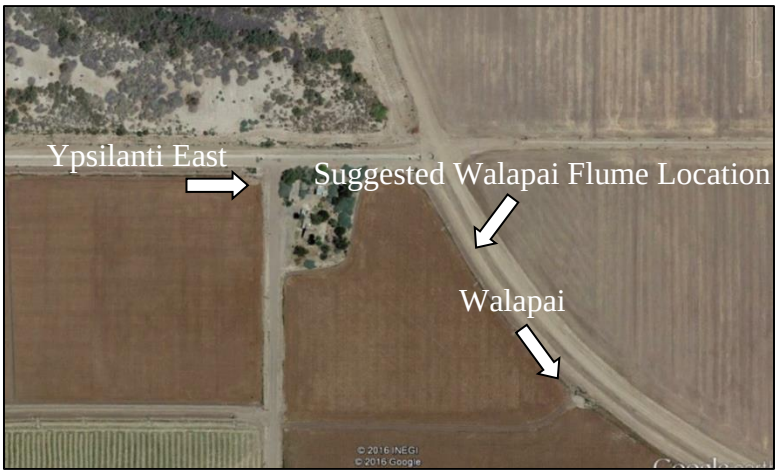

Figure 27.—Turnout into the Walapai from the Ypsilanti East.

Pueblo

The Pueblo branches off of the Cocopah and runs westward along the south edge of Indian Rock Road. At the upper end the Pueblo is concrete lined. An existing ramp flume is installed approximately 85 feet downstream of the culvert exit at

the canal heading. Figure 28 is a Google Earth™ image of the Pueblo turnout from the Cocopah.

Figure 28.—Heading of the Pueblo.

Pima

The Pima turnout from the Cocopah is approximately 2,950 feet upstream from the Pueblo turnout. It is routed along the south edge of Haughtelin Road. Similar to the Pueblo, the heading of the Pima is concrete lined with an existing ramp flume approximately 85 feet downstream from the exit of the culvert through the Cocopah Canal embankment. Figure 29 is a Google Earth™ image showing the upper end of the Pima.

Figure 29.—Heading of the Pima.

Papago

Flow into the Papago is diverted from the Cocopah at a site approximately 3,000 feet upstream from the Pima heading. There is no existing measurement device or

structure at this site. The upper end of the Papago is concrete lined for a distance of approximately 85 feet. The uppermost check in the Papago is located about 12 feet upstream from the end of the lining. A field turnout 15 feet upstream from this check is located on the right side of the canal. There is insufficient canal length between this turnout and the Cocopah to develop favorable hydraulic conditions for installing a flume. Equipping the turnout gate on the Cocopah for gate flow measurement may be the most practical means of measuring flow at this location. Figure 30 is a Google Earth™ image of this location.

Figure 30.—Heading of the Papago.

Paiute

The Paiute branches off from the Cocopah and proceeds westward along the north edge of Ross Road. This reach of the Paiute is concrete lined with an existing ramp flume installed approximately 65 feet downstream from the canal heading. Figure 31 is a Google Earth™ image of the upper end of the Paiute.

Figure 31.—Paiute heading.

Maricopa

The Maricopa is the next to last lateral that branches off from the lower end of the Mohave. The Vomical is the lone lateral downstream along the Mohave from the Maricopa. The upper reach of the Maricopa is concrete lined. An existing ramp flume is installed approximately 70 feet downstream from the canal heading. A check structure in the Mohave is located approximately 30 feet downstream from the Maricopa turnout. By equipping the check gate for gate flow measurement, a radio/control station at this site could monitor flows in the Maricopa as well as flows proceeding downstream to the Vomical. Figure 32 is a Google Earth™ image showing the Maricopa turnout from the Mohave.

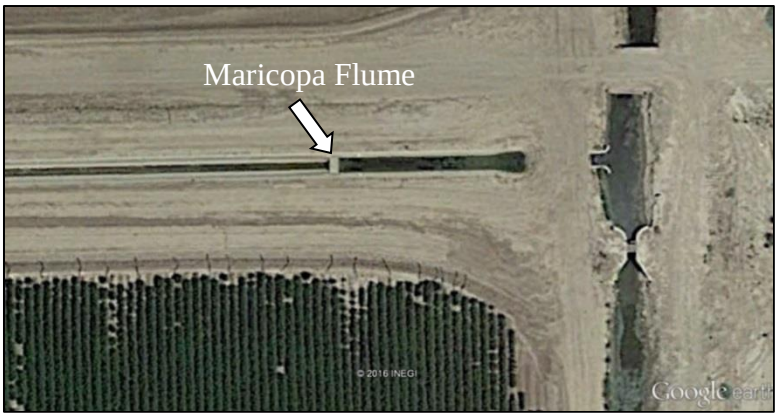

Figure 32.—Maricopa heading.

Klamath

Moving upstream from the Maricopa, the next lateral that branches off from the Mohave is the Klamath. This reach of the Klamath is concrete lined. At the immediate upstream end of the Klamath is a farm turnout gate at the left of the channel. A check structure in the Klamath a short distance below this turnout provides canal stage control for this farm turnout. Approximately 50 feet downstream from this upper check in the Klamath a ramp flume is installed. Hence flow measured at the flume does not account for flow turned out at the upper farm turnout.

To the extent that including the farm turnout flow would be of value the farm turnout gate could be equipped for gate flow measurement. A radio/control station at the site could be programmed to monitor flow over the flume as well as flow through the farm turnout. Figure 33 is a Google Earth™ image of the Klamath heading.

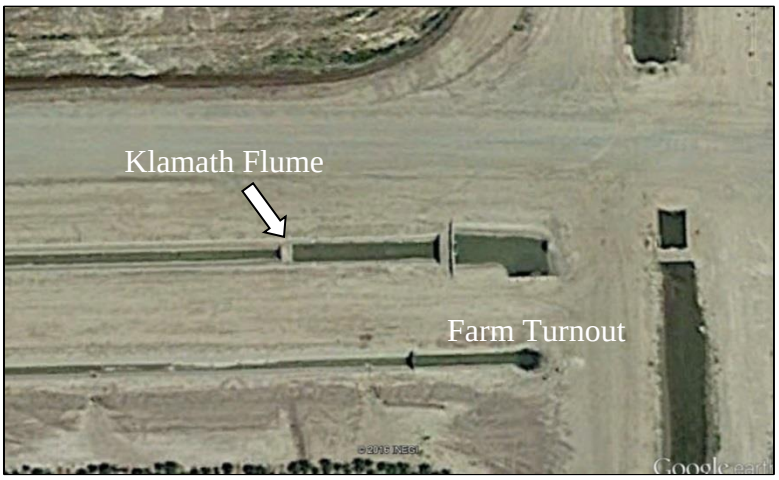

Figure 33.—Klamath heading.

Kiawa

The Kiawa heading is approximately 2,650 feet upstream from the Klamath turnout on the Mohave. The upper reach of the Kiawa is unlined. No measurement device or structure is currently installed. A recommended flume installation site would be a location approximately 55 feet (~ 40 hydraulic radii) downstream from the Kiawa heading. Figure 34 is a Google Earth™ image of the Kiawa turnout.

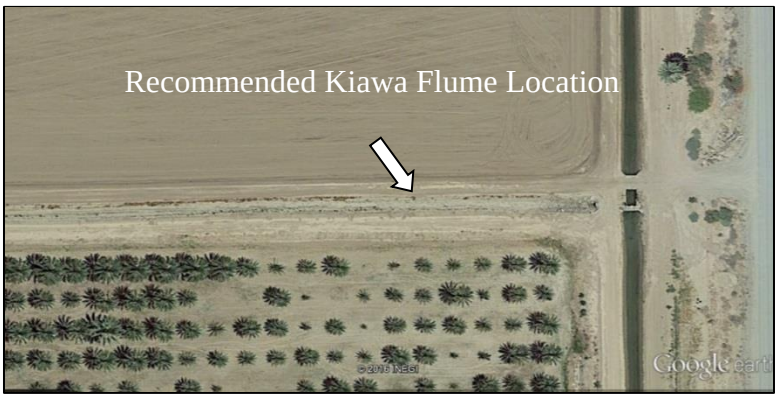

Figure 34.—Kiawa heading.

Hopi

The Hopi branches off the Mohave heading westward along the south edge of 8th Street. The upper reach of the Hopi is concrete lined. A ramp-type long-throated flume is installed approximately 60 feet from the canal heading. Figure 35 is a Google Earth™ image of the Hopi turnout from the Mohave.

Figure 35.—Hopi heading.

Bannock

The Bannock lateral branches off from the RMC approximately 2,150 feet upstream from the Five Gates bifurcation of the RMC and Mohave. The upper end of the Bannock is concrete lined for a distance of approximately 125 feet. A ramp flume is installed approximately 25 feet from the canal heading. Figure 36 is a Google Earth™ image of the Bannock heading.

Figure 36.—Bannock heading.

Acoma

The Acoma is the furthest upstream lateral that branches off the RMC. The upper end of the Acoma is concrete lined for a distance of approximately 75 feet. A laterally-contracted long-throated flume is installed approximately 30 feet

downstream from the canal heading. The canal elevation drops at the flume outlet to ensure the flume will not be subject to excessive submergence. Figure 37 is a photo of the flume at the upper end of the Acoma.

Figure 37.—Acoma heading and flume.

Administrative Boundary Crossings

Seven sites where canals that deliver flow to both the Indian Unit and the Bard Unit cross the Indian Unit – Bard Unit boundary are recommended as monitoring sites. These include:

- Cocopah at Baseline Road – Cocopah turnout to Ranch 5
- Waco at Baseline Road
- Supai at Baseline Road
- Pueblo at Baseline Road
- Pima at Baseline Road
- Papago at Baseline Road
- Yaqui – Zuni split

Locations of these sites are shown in Figure 38.

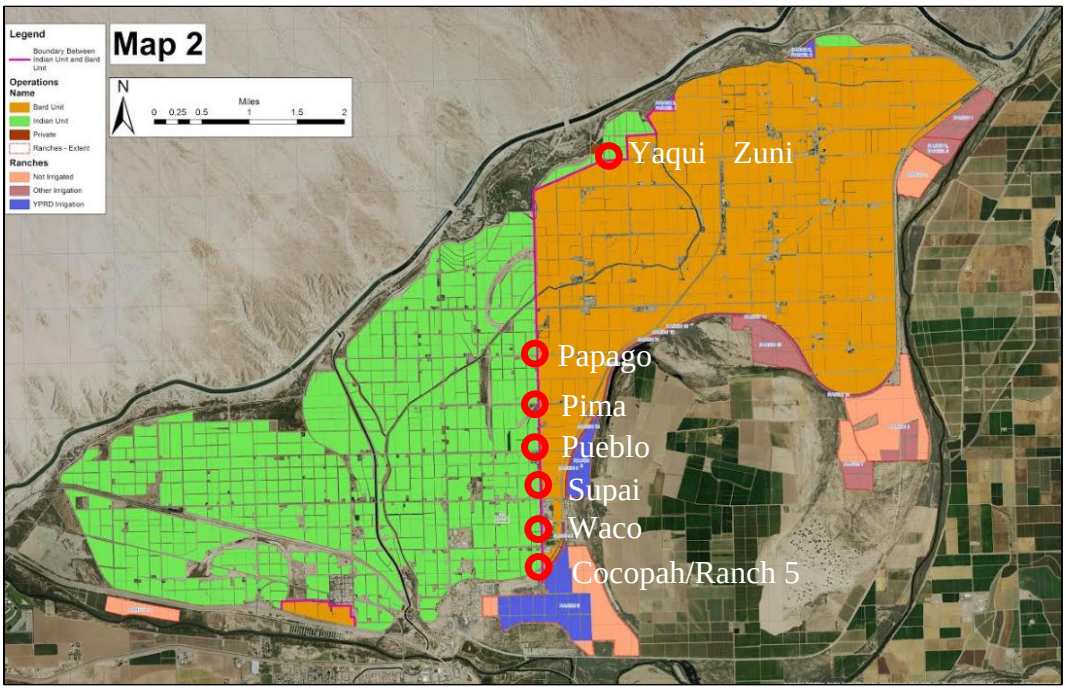

Figure 38.—Administrative boundary crossing sites.

Cocopah at Baseline Road – Cocopah Turnout to Ranch 5

Figure 39 is an image showing the Baseline Road crossing of the Cocopah and the Ranch 5 turnout from the Cocopah. From the Ranch 5 turnout flow is conveyed in a pipe for approximately 1,500 feet. It would be desirable to measure flow continuing down the Cocopah from the Bard Unit into the Indian Unit at this site. It would also be desirable to measure the flow being delivered to Ranch 5. Presently there is no flow measurement device or structure for making either measurement. Pipe-full flow is not assured at the upper end of the pipe. Any flow measurement device installed inside the pipe would be difficult to access for maintenance purposes.

Gate flow measurement for the Ranch 5 deliveries may be the most practical option however options for verifying measurement accuracy are quite limited compared with a site with an open canal downstream from a gate. Re-configuring the Ranch 5 turnout as a two-gate Constant Head Orifice (CHO) structure may be a suitable flow measurement alternative for consideration. This site may warrant investigation into recently developed electronic flow measurement systems for gate sites. For flow that continues downstream in the Cocopah into the Indian Unit it may be feasible to equip the check in the Cocopah at this site for gate flow measurement.

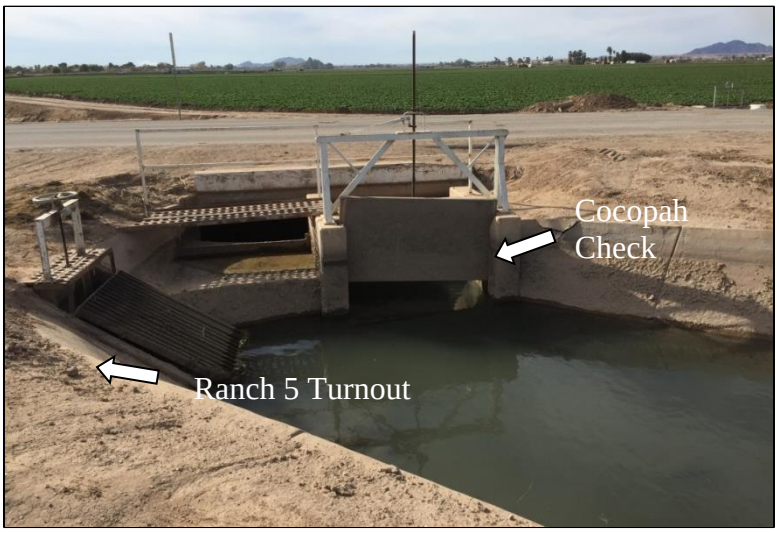

Figure 39.—Cocopah Canal Baseline Road crossing and Ranch 5 turnout.

Waco at Baseline Road

The upper reach of the Waco between the Cocopah and Baseline Road is conveyed through approximately 835 feet of pipe. After passing under Baseline Road, the Waco emerges from the pipe and proceeds westward as an unlined open canal. There is no existing flow measurement device or structure.

Immediately after exiting the piped section, a gate on the left side of the canal controls flow into a field turnout. A check in the Waco a short distance from the field turnout creates the needed canal stage for the field turnout delivery. Both this first field turnout and the adjacent check could be equipped for gate flow measurement in order to measure and record all flows entering the Indian Unit in the Waco. Figure 40 is a Google Earth™ "Street View" image of the site.

Figure 40.—Waco pipe outlet at Baseline Road.

Supai at Baseline Road

The Supai is also conveyed via pipe from the Cocopah turnout to the west side of Baseline Road in the Indian Unit. After emerging from the pipe, the Supai is a concrete lined canal. Flow is measured at an existing ramp-type long-throated flume installed approximately 60 feet downstream from the pipe outlet. Figure 41 shows the flume in the upper reach of the open canal section of the Supai.

Figure 41.—Supai pipe outlet at Baseline Road.

Pueblo at Baseline Road

The Pueblo is a concrete lined canal on both sides of Baseline Road. There is no existing measurement device or structure at baseline road. This would be a candidate site for a pre-fabricated long-throated flume. Figure 42 shows the Pueblo looking west from Baseline Road.

Figure 42.—Pueblo at Baseline Road.

Pima at Baseline Road

The Pima canal is concrete lined on both sides of Baseline Road. At the outset of this project there was no existing measurement device or structure at Baseline Road in the Pima. A pre-assembled laterally-contracted flume was installed as part of the concurrent demonstration monitoring project. Figure 43 shows the recently installed flume in the Pima.

Figure 43.—Flume in the Pima at Baseline Road.

Papago at Baseline Road

The Papago is unlined at the baseline road crossing. There is no existing measurement device or structure at the site. Figure 44 shows the Baseline Road crossing of the Papago looking downstream. Construction of a laterally-contracted long-throated flume is recommended for measuring flow at this site.

Figure 44.—Papago at Baseline Road.

Yaqui – Zuni Split

The location at which the Yaqui crosses from the Indian Unit into the Bard Unit is somewhat of a complex branching node. Flow may proceed southward in the Yaqui into the Bard Unit. This flow may be measured at a ramp flume approximately 130 feet downstream from the Zuni turnout. The Zuni conveys flow in a generally westerly direction. Flow may also be routed eastward from this site into the Yuma Stub. There is no existing flow measurement device or structure to measure flow in the Zuni or into the Yuma Stub. Figure 45 is a Google Earth™ image of the Yaqui – Zuni split.

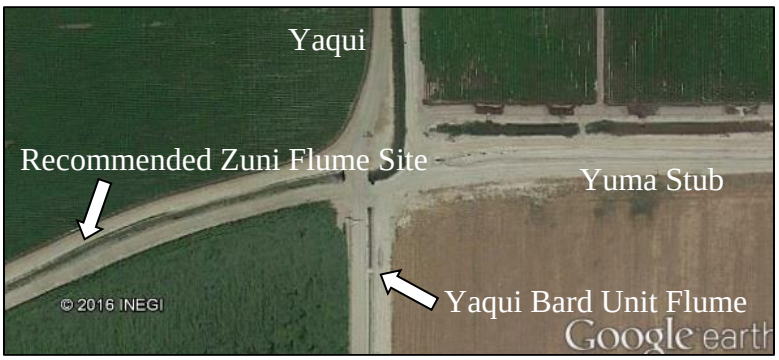

Figure 45.—Yaqui – Zuni Split.

A laterally-contracted long-throated flume is recommended for measuring flow being conveyed in the Zuni. Flow entering the Yuma Stub might be most practically measured by equipping the Yuma Stub turnout gate for gate flow measurement.

YMC Turnouts

Two of the turnouts from the YMC – the 148E lateral and the Seminole lateral have had acoustic Doppler flow meters installed. None of the additional fourteen turnouts had previously been equipped for flow measurement. Data from acoustic doppler sites is fed into the YCWUA SCADA system but has not been passed on to the BWD. Figure 46 shows the locations of the turnouts from the Yuma Main as it passes through the Indian Unit.

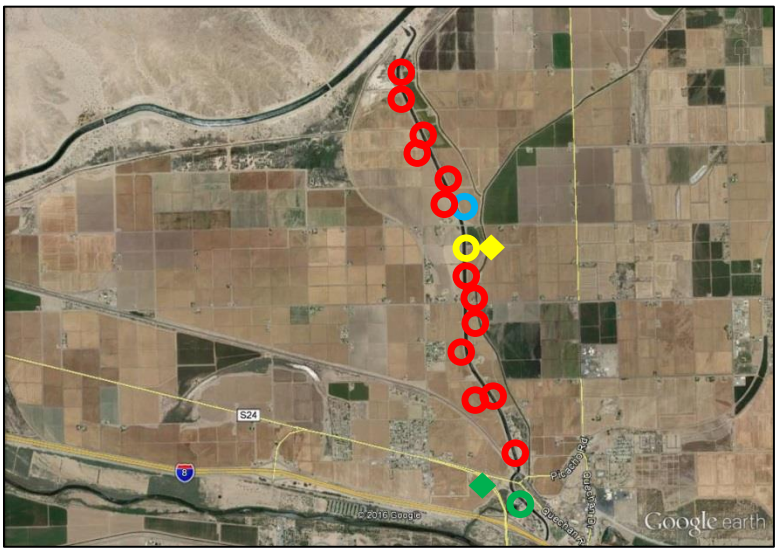

Figure 46.—Turnouts into the Indian Unit from the Yuma Main.

From figure 46, the site marked with a yellow circle is the turnout gate for the 148E lateral which is a piped lateral that serves multiple fields. The yellow diamond shows the location in the pipeline where the ultrasonic flowmeter is installed. At this location the flowmeter is downstream of the first two field turnouts from the 148E pipeline. The site marked with a green circle is the turnout into the Seminole lateral. The green diamond shows where the ultrasonic flowmeter is installed.

Each of the smaller turnouts could effectively be set up as part of a monitoring system by equipping them for gate flow measurement. A demonstration system has been installed on the Yuma Main 103E turnout (blue circle) that provides wireless data access for both the YCWUA SCADA system and for the BWD. This and other demonstration sites are discussed in more detail in the next section of this report.

The flow measurement system currently used for the 148E is not ideal. As currently installed, performing routine maintenance such as cleaning off the acoustic transducer heads would require confined entry procedures. Further, with the flow meter installed downstream of the two uppermost field turnouts, the measurement location is an issue. This site may be a candidate for being reconfigured as a two-gate CHO turnout. This could enable both flow measurement and flow control at the point of turnout from the YMC.

The location of the acoustic doppler gate flow meter in the Seminole is suitable with respect to development of suitable hydraulic flow conditions, being upstream of all turnouts and accessibility for regular maintenance tasks. A concern would be the robustness of the acoustic doppler instrument itself. An evaluation carried out at Reclamation's Hydraulics Laboratory in Denver, Colorado (Heiner and

Vermeyen, 2012) raises significant questions as to the stability of flow measurements produced by most of the commercially available flow meters of this type.

At this open channel site the acoustic doppler unit is more accessible for regular maintenance compared with the unit installed in the 148E pipe. Figure 47 is a photo of the Seminole gage taken in April 2016 in which the acoustic doppler unit on the canal invert is completely covered by sediment and aquatic plant growth. It is recommended that the acoustic doppler flow meter be replaced by installing a laterally contracted flume in this concrete-lined canal that is equipped for Venturi solution flow measurement. This would be a cost-effective upgrade that would represent reduced maintenance needs and more reliable flow measurement accuracy. Laboratory and field testing by Reclamation has shown the Venturi solution as an effective method for measuring flow with long-throated flumes operating under uncertain submergence conditions, (Gill and Niblack, 2009).

Figure 47.—Seminole gage site.

Concurrent Field Demonstration Project

Field Demonstration Project Scope

During the time the study of the Reservation Division delivery system was ongoing, engineers looking into opportunities for integration of electronic monitoring, control and communications were also working with the YAO Water Conservation Field Services Program (WCFSP) in providing technical assistance to irrigation systems in the YAO service area. Establishing a demonstration-scale pilot monitoring and data collection project within the Reservation Division was seen by the WCFSP as an activity that could complement the ongoing delivery system study and provide momentum to subsequent implementation of recommendations developed in the study

A paper on the demonstration project was presented at the US Committee on Irrigation and Drainage conference held in Albuquerque NM in October of 2015 (Gill and Walker, 2015). Features of the field demonstration project included setting up four field sites, establishment of a base station at the BWD office, and one mobile "ditchrider" unit (DRU). The field sites included the Ypsilanti diversion off the All-American Canal, the 103E turnout from the YMC, the Pima Canal where it crosses into the Indian Unit from the Bard Unit and the Hopi lateral heading. All components were equipped with programmable controller units with integral UHF radio modules. Figure 48 shows the demonstration project layout.

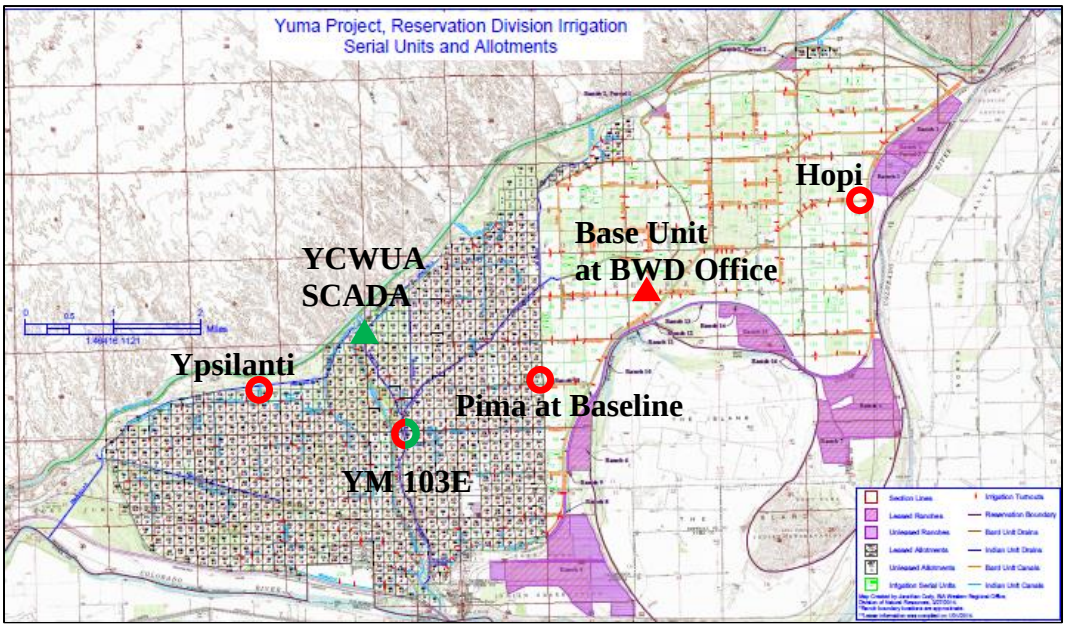

Figure 48.—Demonstration project sites.

Ypsilanti

The Ypsilanti site had been set up in 2001 as a demonstration site for a prototype automated gate controller. The manufacturer of the prototype controller discontinued production within a few months of the time the demonstration site was established. For the present project the newly installed control unit is setup to perform flow monitoring functions only. All hardware is in place for the addition of automated or remotely controlled gate operation in the future if so desired.

Presently a bubbler level sensor equipped with a three-output solenoid valve manifold is monitoring levels and computing flows at 1) the Cipolletti weir measuring all flow being diverted from the All-American, 2) flow passing over a ramp-type long-throated flume in the Ypsilanti West lateral and 3) flow passing over a similar ramp-type long-throated flume in the Ypsilanti East lateral. Figures 49, 50, and 51 are photos of the Cipolletti weir and the Ypsilanti East and Ypsilanti West flumes, respectively.

Figure 49.— Ypsilanti Cipolletti weir.

Figure 50.— Ypsilanti East flume.

Figure 51.— Ypsilanti West flume.

Yuma Main 103E

The Yuma Main 103E turnout gate was modified by removing the "jack" type gate operator and replacing it with a threaded stem with hand-wheel nut gate operator. A gate position sensor featuring a gear that engages in the gate stem threads was installed and calibrated to sense vertical gate opening. A bubbler level sensor equipped with a two-output solenoid valve was installed with bubbler taps located upstream and downstream from the gate.

Flow is calculated at this site using orifice flow calculations based on gate open area and head differential across the gate. In addition to the integral UHF radio, an auxiliary Modbus port on the controller at the site is linked to a 900 MHz spread spectrum radio that can communicate with a similar radio at the YCWUA SCADA hub (green triangle in Figure 48) located at the hydropower plant at the heading of the Yuma Main. Figures 52 and 53 show the Yuma Main 103E site before and after being configured for the demonstration project.

Figure 52.—103E turnout with old "jack" gate operator.

Figure 53.—Upgraded 103E site.

Pima Canal at Baseline Road

Prior to the demonstration project there was no flow measurement structure at this location. BWD management expressed a preference for laterally-contracted long-throated flumes due to maintenance issues with upstream sediment accumulation they have experienced with ramp-type flumes. A laterally-contracted flume constructed using composite decking planks was installed at the site.

During visits to the site prior to installation of the flume it was noted that ponded water conditions frequently exist. The new flume was configured to take water level measurements both in the approach section and in the throat section of the flume. By measuring both levels, ponded water could be sensed and identified as a "no flow" condition. In addition the two water level measurements could be utilized to calculate flow using the Venturi solution which would enable measurement accuracy to extend into submergence conditions beyond the modular limit for flow calculated using only the upstream level and a critical flow flume rating equation. Figure 54 shows the Pima Canal demonstration site during construction.

Figure 54.—Flume under construction in Pima at Baseline Road.

Hopi Lateral Heading

The Hopi lateral heading had also been previously set up as a demonstration site. In 2006, a prototype flow monitoring device developed at Reclamation's Hydraulics Laboratory called the continuous flow meter (CFM) was installed at this location. The CFM was developed as a stand-alone device with no communications capability. At the time the equipment for the current

demonstration project was installed, the CFM was not operable.
Existing equipment at the Hopi site that is used for the current demonstration project included a ramp-type long-throated flume and pipe pole with an electrical enclosure to house instrumentation. The Hopi site was reconfigured by installing a programmable control unit with integral UHF radio and a bubbler level sensor with a two-output solenoid valve. From examination of high water marks on the concrete lining both upstream and downstream from the flume it appeared highly likely that the flume is operated at times with submergence in excess of its modular limit. Bubbler ports were installed to read water levels both in the approach section and the throat section of the flume to enable flow calculation using the Venturi solution in order to extend the ability to get accurate flow measurements at submergence levels beyond the modular limit. Figure 55 shows the reconfigured Hopi demonstration site.

Figure 55.—Hopi lateral heading.

BWD Office Base

A base station configured using a programmable control unit with integral radio similar to the field installations was installed on the east wall of the ditchrider room located at the south end of the BWD office building. An antenna mast with an omni antenna was installed near the base station location. A display and keypad were installed in the cover of the electrical enclosure housing the radio/control equipment.

A program loaded into the base controller provides on-screen prompts that direct user-entered keystrokes that enable the user to select a field site, then retrieve current measurements taken at the field site. The base unit is also linked to a PC

via RS232 serial linkage. Software loaded on the PC directs automated polling of each field site at a user-selected interval. During these polling cycles, data logged onsite at each field site that has not previously been retrieved is collected and written to a CSV file on the PC hard drive. Data is written to separate files for each field unit. New files are automatically started at the beginning of each month. The files in CSV format may be opened and read in Excel. Figure 56 shows the newly installed base antenna.

Figure 56.—BWD Office base antenna.

Ditchrider Unit (DRU)

The mobile unit supplied to BWD staff as part of the demonstration project is basically the same programmable control unit with integral radio used for the field sites. It is installed in a small plastic enclosure and is equipped with a cigarette lighter power cord. A magnetic mount antenna that may be detached from the control unit is typically mounted on top of the cab of a ditchrider's pickup. Essentially, the same program that is loaded in the base station unit is installed in the DRU. Figure 57 shows the DRU unit supplied to the BWD staff.

Figure 57.—Ditchrider unit.

The demonstration project proved to be complementary to the study of the Reservation Division water delivery system in multiple ways. Field sites included in the demonstration project each represent one of the types of priority sites for a monitoring/data archiving system. Installation of the field sites with assistance from BWD staff provided opportunities to enable BWD staff to gain a level of familiarity with installation and operation of the various system components.

The limited-scope project includes sufficiently diverse site conditions, spatially distributed locations and functionality range that will enable BWD and the water delivery customers to experience and assess the level of benefits that might be realized from a more comprehensive system. The demonstration project represents a network skeleton that can be readily expanded. The demonstration project also provides a tool for project engineers to assess the degree to which use of the technology will be embraced by BWD management and staff which can be indicative of the level of in-house expertise BWD can be anticipated to attain.

Summary of Recommendations

A table summarizing recommended flow measurement and monitoring sites along with per-site cost estimates is included in the Appendix of this report. The monitoring network being recommended would include 46 monitoring stations, 1 office base station, and 3 ditchrider mobile units.

NOTE: Forty-nine total sites have been identified under the six site classifications. At three of these sites a monitoring station will be able to perform monitoring functions for sites listed under two classifications. These include the Ypsilanti diversion from the All-American as well as the headings of the Ypsilanti East and the Ypsilanti East; the RMC-Mohave split along with flow over the spill weir at the same site; and the Cocopah at Baseline Road along with the Ranch 5 turnout from the Cocopah at the same location. Thus 46 total monitoring stations are needed for the 49 total listed sites.

Of these totals, all equipment is in place for 4 monitoring stations, the office base station and one DRU as part of the demonstration project. Sixteen of the monitoring stations are Yuma Main turnouts that will need to be equipped with dual radio systems. One of these 16 sites with dual radio system was part of the demonstration project.

At some of the sites, flow (or spill) leaving in more than one direction would be measured. Among the delivery network sites, there are 21 existing flumes and one Cipolletti weir. Construction of 8 additional flumes and an additional weir is recommended.

It is also recommended that two of the existing flumes – at the head of the Tonawanda and the Cocopah mid-system flume be removed and replaced. The flume at the head of the Tonawanda is improperly located and has unsuitable hydraulic conditions in the approach flow. The ramp-type flume in the Cocopah has proven to create a significant maintenance problem due to the amount of water that is retained in the canal above the flume when water is turned out for maintenance tasks.

In addition to these flume and weir recommendations, it is recommended that flow control gates be equipped for gate flow measurement at 29 locations. At one of these sites (the Yuma Main 103E turnout) the gate site has already been updated as part of the demonstration project.

At the two sites where acoustic doppler flow meters are currently installed – Yuma Main turnouts 148E and the Seminole – replacement of these units is recommended. A flume equipped for Venturi solution flow measurement is recommended for the Seminole (one of the 8 recommended new flumes). Flow

measurement at the 148E turnout gate site is recommended. Reconfiguration of the 148E turnout as a two-gate CHO measurement/flow control structure may be a cost-effective alternative.

At some of the recommended monitoring sites there is potential to add automated or remotely operated gate control in the future. Programmable electronic control equipment being proposed for these sites would have the capability to perform these control functions to enable cost-effective future operational upgrades.

The parallel demonstration project provided an opportunity to verify that systems and site configurations being recommended are viable and functional. For example, flow data from turnouts along the Yuma Main needs to be available in real time for both YCWUA and BWD. Equipment installed on the 103E turnout as part of the demonstration project has shown that this may be accomplished with independent communications systems linked to a common programmable control unit. Data may be simultaneously polled by data collection systems for each entity without interfering with each other.

Cost Summary and Conclusions

Estimated Installed Cost Summary

Electronic Radio/Control Stations		
4 Demo Project field stations	$49,230	
42 Additional recommended sites		$519,810
Recommended New and Upgraded Flow Measurement Structures		
2 Demo Project field stations	$6,290	
32 Additional recommended sites		$289,425
Office Base Station		
Installed as part of Demo Project	$11,660	
Ditchrider Mobile Units		
1 Provided as part of demo Project	$2,200	
2 Additional recommended		$4,400
Remaining Estimated Project Costs		
		$813,635

An itemized table listing estimated costs for each field site is included in the appendix of this Technical Memorandum.

Conclusions

The recommended monitoring and data collection network along with the recommended flow measurement upgrades can be cost effective enhancements for daily management of the complex water delivery network in the Reservation Division. Incremental implementation of the electronic technologies would be advisable to allow the BWD staff to develop a comfort level with the technology that can develop into in-house capabilities in operating and maintaining the equipment.

References

Gill, T. and M. Niblack. 2009. *Flow Measurement With Long Throated Flumes With Uncertain Submergence.* Yuma Project, Lower Colorado Region, Bureau of Reclamation.

Gill, T. and K. Walker. 2015. *Demonstration Flow Monitoring and Data Collection System for the Yuma Project Reservation Division.* Proceedings: Emerging Issues in Water Management Governance, United States Committee on Irrigation and Drainage, Albuquerque, New Mexico, 11/17-20.

Heiner, B. and T. Vermeyen. 2012. *Laboratory Evaluation of Open Channel Area-Velocity Flow Meters.* Hydraulic Laboratory Report HL 2012-03, Bureau of Reclamation, Denver, Colorado.

Appendix

Recommended Flow Measurement and Monitoring Sites

Site	Control Option?	Measurement Structure	Recommended Structure Upgrade?	Cost Estimates	
				Radio/Control Equipment	Flow Measurement
Site Type: Inflow					
RMC Heading	Monitoring Only*	Rated section	Install flume	$11,000	$75,315
Titsink Canal Heading	Monitoring Only*	Stream gaged	Install flume	$11,000	$13,000
Yaqui	Monitoring Only*	Flume	N/A	$11,000	
Pontiac	Monitoring Only*	Flume	N/A	$11,000	
Ypsilanti	Control can be added	Cipolletti weir	N/A	Demo Site ($13,040)	
Site Type: Major Spill					
Spill at RMC/Mohave Split	Monitoring Only**	Spill weir	N/A	$13,040	
Spill Into Cocopah Drain Canal	Monitoring Only	Non-standard Structure	Reconfigure as a weir	$11,000	$1,600
Tonawanda Spill Into Drain #11	Control can be added	None	New gate measurement	$12,140	$2,190
Site Type: Key Locations Along Major Canals					
Ypsilanti East – Ypsilanti West	Control can be added	2 Ramp-type long-throated flumes	N/A	Demo Site (Same Unit Shown in Inflow)	
Pequod – Navajo	Control can be added	2 Ramp-type long-throated flumes	N/A	$13,040	
Cocopah Flume	Monitoring Only	Ramp-type long-throated flume	Replace with laterally-contracted flume	$11,000	$17,800
RMC – Moqui	Control can be added	None	New gate measurement (3 gates)	$13,040	$6,750
RMC – Apache	Monitoring Only	None	New flume in Apache	$11,000	$4,100
RMC – Mohave	Control can be added	None	New gate measurement (5 gates)	Same Unit Shown in Major Spill	$10,950
Site Type: Lateral Headings					
Tonawanda	Control can be added	Ramp-type long-throated flume	Replace improperly installed flume	$12,140	$21,600
Comanche	Control can be added	Ramp-type long-throated flume	N/A	$12,140	
Walapai	Control can be added	None	New flume	$12,140	$13,000
Pueblo	Control can be added	Ramp flume	N/A	$12,140	

Recommended Flow Measurement and
Remote Monitoring Upgrades for Delivery System Operations

Site	Control Option?	Measurement Structure	Recommended Structure Upgrade?	Cost Estimates	
				Radio/Control Equipment	Flow Measurement
Paiute	Control can be added	Ramp flume	N/A	$12,140	
Maricopa	Control can be added	Ramp flume	N/A	$12,140	
Klamath	Control can be added	Ramp flume	N/A	$12,140	
Kiawa	Control can be added	None	New laterally-contracted long-throated flume	$12,140	$13,000
Hopi	Control can be added	Ramp flume	N/A	Demo Site ($12,140)	
Bannock	Control can be added	Ramp flume	N/A	$12,140	
Acoma	Control can be added	Laterally-contracted long-throated flume	N/A	$12,140	
Site Type: Administrative Boundary Crossing					
Cocopah at Baseline Rd	Control can be added	None	New gate measurement	$13,040	$2,190
Ranch 5 to/from Cocopah	Control can be added	None	New gate measurement	Same Unit as Above	$2,190
Waco at Baseline Rd	Control can be added	None	New gate measurement (2 gates)	$12,140	$4,380
Supai at Baseline Rd	Monitoring Only	Ramp flume	N/A	$11,000	
Pueblo at Baseline Rd	Monitoring Only	None	N/A	$11,000	$4,100
Pima at Baseline Rd	Monitoring Only	Demo Laterally-contracted long-throated flume	N/A	Demo Site ($11,000)	($4,100)
Papago at Baseline Rd	Monitoring Only	None	New laterally-contracted long-throated flume	$11,000	$13,000
Yaqui – Zuni Split	Control can be added	Ramp flume (Yaqui) Gate measurement (Yuma Stub)	New laterally-contracted long-throated flume (Zuni)	$13,040	$15,190
Site Type: Yuma Main Turnouts (All Dual Radio Sites)					
Seminole	Control can be added	Acoustic doppler flow meter	New laterally-contracted long-throated flume	$14,190	$4,100
148E	Control can be added	Acoustic doppler flow meter	Two-gate CHO Turnout	$15,090	$36,500
103E	Monitoring Only	None	Demo Site (new gate flow)	Demo Site ($13,050)	($ 2,190)
13 Additional Small Turnouts	Monitoring Only	None	New gate flow	(13 at $13,050) = $169,650	(13 at $2,190) = $28,470

*An additional radio/control installation is recommended at this site if gate control is to be added in the future.

**Gates controlling flow down RMC and Mohave may be controlled by this control unit monitoring spill.