FINAL

Middle Creek Early Warning System Feasibility Study

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Introduction

Under the direction of the Montana Department of Natural Resources and Conservation (DNRC), Water & Earth Technologies, Inc. (WET) and David Ford Consulting Engineers, Inc. (Ford) evaluate the feasibility and cost of installing an early warning system (EWS) for Middle Creek Dam in this report.

Middle Creek Dam is located approximately 16 miles south of Bozeman, Montana in Gallatin County. The 125-foot high earthfill dam is an on-stream structure of Hyalite Creek (also called Middle Creek) that provides approximately 10,000 acre-feet of active storage. The water is used for irrigation and municipal supply for the City of Bozeman. The total tributary drainage area to Hyalite Reservoir is approximately 27.8 square miles.

The DNRC under the direction of the State Water Projects Bureau, Water Resources Division, supervises the operation and maintenance of Middle Creek Dam. The day-to-day operations of the dam lie with the Middle Creek Water Users Association (MCWUA). Filling of the reservoir usually starts in May or June. It is desirable to fill the reservoir before the spring runoff has ended and inflows must be passed to meet downstream water rights. The release of stored water usually begins in July.

The dam was finished in 1951. Rehabilitation work, under the direction of DNRC, was completed in 1992. The rehabilitation work consisted of raising the embankment by 10 feet, replacing the principal spillway and constructing an auxiliary spillway.

A dam breach analysis was conducted by the DNRC in 1990 to delineate the inundation area below the dam. Two dam breach scenarios were evaluated to determine the extent of the downstream flooding. The first scenario was a sudden breach resulting from an earthquake or structural failure. The second scenario considered a breach associated with the probable maximum flood (PMF) above the reservoir. Only the inundation area resulting from the PMF breach is currently depicted because there was little difference between the inundation areas resulting from each scenario. The area from Middle Creek Dam downstream to the confluence of the Gallatin River with the Missouri River is shown (Figure 1) along with the inundation boundary for the worst-case, flood-induced dam failure.

Populated areas exist below the dam along Hyalite Creek in the Gallatin Valley. Most of the homes that lie in the flood inundation area were built after the dam was constructed in 1951. Several areas would be impacted in the event of a dam failure (Table 1).

Table 1. Populated Areas below Middle Creek Dam

Facility along Hyalite Creek	Distance Below Dam
Langohr Springs Campground (summer campers)	4.2 miles
Canyon Mouth (start of residential population area)	9.6 miles
Four Corners	18.2 miles
Interstate 90 East of Belgrade	24.1 miles
Interstate 90 West of Belgrade	31.7 miles
Logan	42 miles

The DNRC is working to improve the current dam safety program at Middle Creek Dam by: (1) installing an automated instrumentation system at the dam to monitor reservoir and embankment conditions in 2008 and (2) evaluating the feasibility and cost of implementing an early warning system that would alert emergency response personnel in the event of a dam failure. This report is prepared to address item two.

Figure 1. Middle Creek Dam Inundation Area

Early Warning System Feasibility

The scope of this report is to evaluate the feasibility and probable cost of installing an early warning system (EWS) at Middle Creek Dam.

An early warning system is beneficial if it provides enough additional time to emergency responders so that life and property can be safely removed from the flood inundation zone in the unlikely event of dam failure.

An early warning system is composed of several components that must function together. The components include:

1. a monitoring network to detect dam failure,
2. a telemetry system to communicate the occurrence of dam failure to emergency responders in real-time,
3. a notification system to notify the public when dam failure has occurred, and
4. plans for evacuation so that the public knows what to do and where to go.

This feasibility study evaluates whether these components can be successfully established for Middle Creek Dam.

The feasibility study also considers the cost and reliability of an early warning system. Reliability is evaluated in terms of component redundancy and fault tolerance so that the system has a high probability of functioning as designed during an emergency.

The early warning system must function in an automated fashion independent from other instrumentation systems. The DNRC has plans to implement an instrumentation system for operational purposes in 2008. This system will monitor phreatic conditions within the earthen embankment, drain flows and the water surface elevation in the reservoir. The automated instrumentation system will be installed and maintained by the DNRC and will be independent from the early warning system. The automated instrumentation system will monitor the dam to identify conditions that may lead to dam failure such as piping and erosion. This system will help the DNRC to evaluate the safety of the dam on a continuing basis from their office in Helena and provide information relevant to long-term maintenance requirements for the dam.

An important assumption within this feasibility study is that the instrumentation and equipment associated with the early warning system are completely separate from the automated instrumentation upgrade planned by the DNRC. However, there may be benefits to sharing of equipment between the two systems, to simplify this feasibility study the two systems are treated separately. DNRC may decide to combine aspects of the two systems.

Population at Risk below Middle Creek Dam

The Gallatin County Geographic Information Services (GIS) department has identified and mapped all the structures (Allen Armstrong, Gallatin County GIS, Bozeman, MT) in the county that are below Middle Creek Dam along Hyalite Creek (Figure 2).

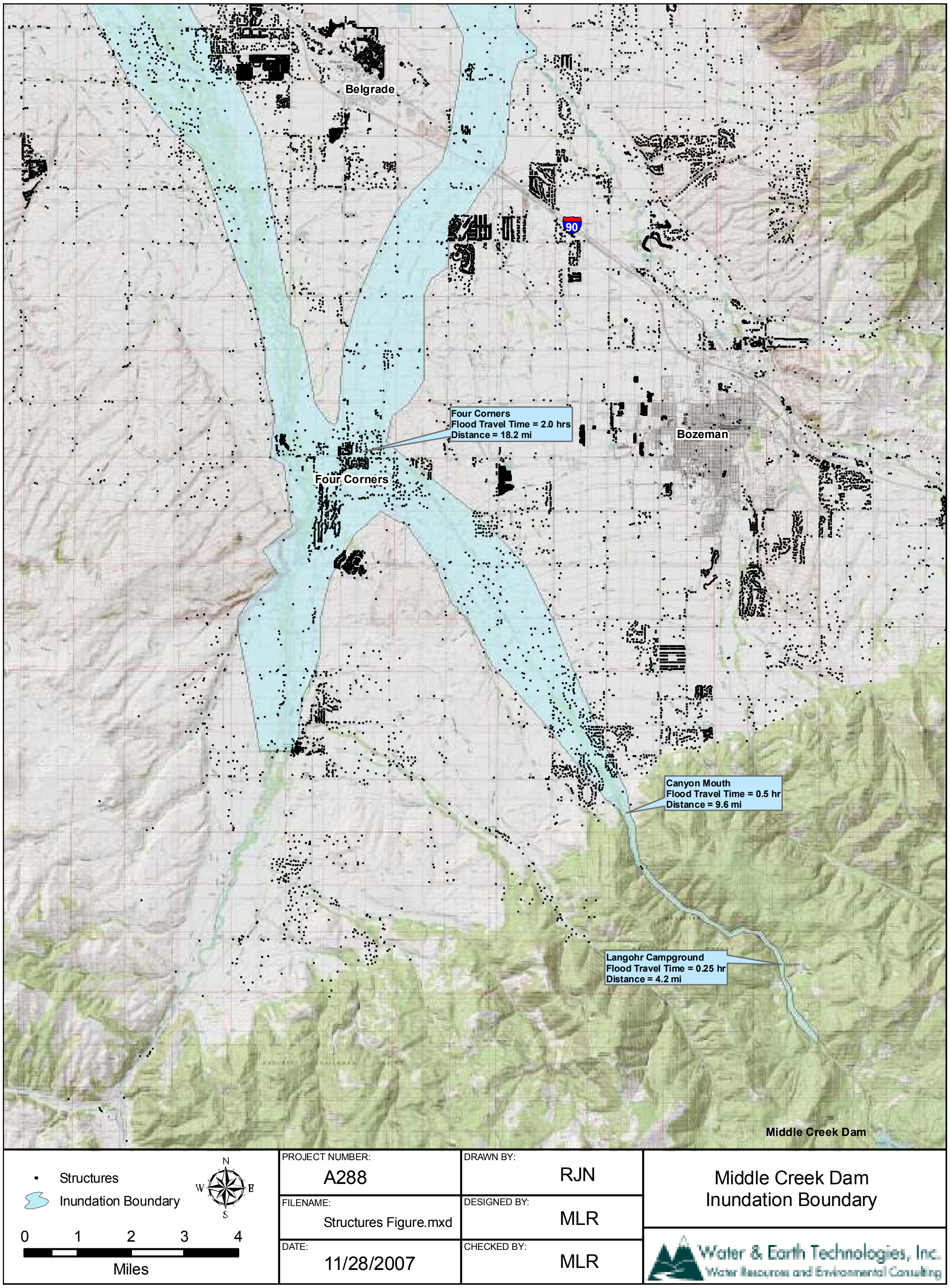

Figure 2. Middle Creek Dam Populated Areas and Flood Inundation Boundary

A number of permanent residents live along Hyalite Creek below the dam from the canyon mouth to Belgrade and beyond. A significant population is at risk from the canyon mouth to the Four Corners area. These residents have the shortest amount of time to evacuate in the event of dam failure because they live within twenty miles of the dam in areas where flood travel times range from thirty minutes to two hours. Residents living downstream of the Four Corners area have more time to evacuate because flood travel times are greater than two hours.

During the summer months, a transient population exists down stream of the dam in the form of campers, hikers and fisherman. The Langhor Springs Campground, located on Forest Service land only four miles below the dam, would be impacted by flood waters with travel times on the order of fifteen minutes.

The population at risk is quantified from the canyon mouth to Four Corners by overlaying the flood inundation area with the structure location map (Figure 2). The type and number of structures (including Four Corners) is shown (Table 2). A rough estimate of the population is computed using 2000 Census Bureau average household data. The population at risk from the canyon mouth to the Four Corners area is on the order of 2,800 residents. These residents are permanent and are present in the inundation area at night. During the day, these residents may still be in the flood inundation area but at other locations such as schools, commercial areas and garages.

Table 2. Estimated Population at Risk from Canyon Mouth to Four Corners

Structure Type	Structure Count	Occupancy at Night	Persons per Household*	Population at Risk
Church	1	No	--	--
Clinic/hospital	1	Yes	50 (estimate)	50
Commercial	158	No	--	--
Farmstead	48	Yes	2.46	118
Fire station	1	Yes	10 (estimate)	10
Garage	5	No	--	--
Government	1	No	--	--
Multi-family	31	Yes	2.46	76
Residential	834	Yes	2.46	2,051
School	5	No	--	--
Trailer	220	Yes	2.46	541
TOTAL	**1,305**	**--**	**--**	**2,846**

* - U.S. Census Bureau, 2000 census information, average persons per household in Gallatin County, Montana was 2.46.

Current Operations at Middle Creek Dam

The operation of Middle Creek Dam is such that it captures spring runoff to make irrigation deliveries beginning in July. The reservoir is full or nearly full from approximately June through August. These are peak months for outdoor recreation and campers and fisherman are prevalent in the canyon below the dam.

A dam tender is present almost daily during the irrigation season to provide active visual inspections of the dam. The dam tender does not live at the dam but travels to the dam from Bozeman. The dam tender is not present on a daily basis at Middle Creek Dam from the period October through April.

Cell phone coverage throughout the canyon is non-existent. Cell phone coverage at the dam is marginal. A casual observer or dam tender witnessing a breach or increased water in the canyon would not be able to contact authorities using a cell phone. Reliable cell coverage begins at the canyon mouth. The dam tender's ability to communicate begins after he drives back down the canyon nearly 10 miles to where his cell phone is back in coverage.

Risk of Sudden Failure

A comprehensive analysis of Middle Creek Dam to determine structural deficiencies that could lead to failure is not part of the feasibility study.

Middle Creek Dam was rehabilitated in 1992 to comply with current federal dam safety standards and the Montana Dam Safety Act. The embankment crest was raised by 8 feet to an elevation of 6730.0 feet. The principal spillway crest was raised to 6721.0 feet and can pass the 500-year event. An emergency spillway was constructed with a crest elevation of 6723.0 feet. In its current state, Middle Creek Dam can safely pass the PMF with zero freeboard. A failure due to hydrologic conditions and subsequent overtopping of the dam is extremely unlikely due to the size of the spillway.

Warning Time and its Impact on Emergency Evacuation

Warning time is a key factor in reducing the number of fatalities resulting from dam failure and associated flooding. The importance of timely warnings has been qualitatively studied in a report published by the Bureau of Reclamation (Graham, DSO-99-06, September 1999). Warning time is considered to be initiated once the first person begins to notify people and not necessarily at the time when a formal notification process begins. The following examples from the Graham report illustrate warning time and its importance in saving lives.

The Teton Dam, located in Idaho, failed during its initial filling at noon on June 5, 1976. At the time there were 25,000 people living below the dam that were at risk. Failure occurred during the day and warnings to downstream areas occurred about 1 hour and 15 minutes prior to dam failure. Eleven people died in the flood. Graham estimates that if the dam failure had occurred with no warnings, hundreds of lives would have been lost. Teton Dam did not have an early warning system and warnings were issued based on visual observations made by engineers at the dam.

The Laurel Run Dam, located in Pennsylvania, failed at night in 1977. Failure of this dam claimed the lives of 40 of the 150 people at risk below the dam. Because the failure occurred at night, no warnings were issued. Graham estimates that fatalities could have been near zero had warnings been issued to the people living in the valley below the dam.

The largest loss of life from any dam failure in the U.S. occurred when the Johnstown Dam failed at approximately 3:00 PM on May 31, 1889. The earthfill dam was 36 years old when it failed. It was 72 feet high and contained 11,500 acre-feet of water. A storm upstream of the dam caused it to overtop and fail, killing about 2,200 people mostly living in Johnstown. Nearly all of the fatalities occurred within the first 14 miles downstream of the dam. Warnings were issued as early flood waters preceded the major flooding associated with the complete failure of the dam. A dam tender traveled by horseback to a nearby community about 3 hours before dam failure and a message was telegraphed to Johnstown describing the danger but the warning was largely ignored (Graham, 1999). Loss of live could have been reduced, had people heeded the warning.

The importance of warning time is clear from the historical cases studied by Graham. Warning time has typically been established by a human being through visual observation and confirmation of dam failure and resulting flooding. Warning time can also be established using automated instrumentation in the form of an early warning system to observe conditions at and below the dam.

Warning Time Relative to Flood Travel Time

The goal of an early warning system at Middle Creek Dam is to detect dam failure and to provide notification of such failure to emergency responders. Responders must then decide to act on the notification and implement their emergency response plan, including initiating notification of the public using the methods that have been selected to encourage individuals in harm's way to evacuate.

For the purpose of this feasibility study, warning time is defined as the elapsed time between the initiation of an official evacuation warning and the arrival of flood waters. Warning time must be considered relative to flood travel times. If the flood travel time is very short, the early warning system will not provide enough warning time to help evacuate people.

Flood travel time is defined as the time required for water to move from the dam to a downstream populated area. The travel time is a function of the speed of flood water and the location of the population at risk. Flood travel time represents a fixed quantity in the feasibility analysis. Once the dam breaks, only a fixed number of minutes are available to remove people from harms way. The benefit of an early warning system must therefore be referenced to the flood travel time.

If Middle Creek Dam were to fail instantaneously, the travel time for the resulting flood water to reach various locations downstream is summarized (Table 3). These travel times were developed through a modeling study completed under the direction of the DNRC.

Table 3. Flood Travel Times from Middle Creek Dam

Facility along Hyalite Creek	Distance Below Dam	Approximate Flood Travel Time
Langohr Springs Campground	4.2 miles	15 minutes
Canyon Mouth	9.6 miles	30 minutes
Four Corners	18.2 miles	120 minutes
Interstate 90 East of Belgrade	24.1 miles	258 minutes
Interstate 90 West of Belgrade	31.7 miles	414 minutes

Evaluation of Warning Time with and without an Early Warning System

The benefit of an early warning system is evaluated by comparing the warning time available with an early warning system to the warning time available without an early warning system. In order to determine if an early warning system can increase warning time, three distinct components of the warning process must be introduced and quantified for the scenarios with and without an early warning system. These components include: notification time, decision time and response time. Warning time is the flood travel time less the sum of these.

Notification time represents the cumulative time to detect dam failure and to communicate this information to the authorities. In the absence of an early warning system, the notification time consists of an individual located at the canyon mouth that has visually observed flood waters and makes a 911 call to report flooding. Observation of flooding within the canyon or at the dam itself is irrelevant because cell phone coverage is non-existent in the canyon. It is also unlikely that the dam tender will be able to observe failure at the dam and drive down the canyon to make a call to authorities.

In the absence of an early warning system, the notification time is estimated using information provided by the Graham report (Graham, DSO-99-06, Table 2, September 1999) for the following conditions:

1. earthfill dam.
2. failure mode is piping with full reservoir during normal sunny-day weather.

Under these conditions, dam failure notification would be issued approximately 15 minutes (day time failure) to 60 minutes (night time failure) after floodwaters reach the first populated area. The first populated area along Hyalite Creek would be the canyon mouth. A casual observer at the canyon mouth would see the flooding and make a 911 call to the proper authorities. The total notification time includes the 15 to 60 minutes estimated from the Graham report plus the travel time for the water to reach the canyon mouth.

With an early warning system, the notification time is shorter than without an early warning system because an automated monitoring system will detect flood waters below the dam and report the observation via a real-time telemetry system directly to the authorities.

The notification time with an early warning system is estimated to be approximately 1 to 5 minutes. This time represents the latency involved with the monitoring system to detect rising flood waters, to establish a critical condition through a set of predetermined logic parameters and to communicate this information to the emergency responders. Some amount of time is required for the water from the dam to buildup at the monitoring locations to the point where the float trigger switches are activated. There is also travel time associated with the flood wave as it makes its way down to the stream monitoring location one mile below the dam.

Decision time represents the time required by authorities to interpret and confirm the information received and to initiate mitigation actions. Without an early warning system, the decision time is estimated to be 5 to 15 minutes because authorities may require more than one individual to call 911 to confirm flooding.

With an early warning system, the decision time may be reduced to 1 to 5 minutes if the authorities have an understanding of the early warning system (instrumentation and telemetry) and have confidence that the system operates in a reliable manner. The early warning system instrumentation should be designed to provide redundant data. Two independent stations that could detect dam failure should be provided so that even if one station malfunctions, the other can provide notification. Ideally, if both stations are operating, responders will have confirmation that emergency conditions exist from the lower stream station. The flood travel time to the lower station is taken into account in the decision time.

Response time represents the time required of emergency staff to notify the public. This time is not a function of an early warning system and is the same with or without an early warning system. An estimate of approximately 8 minutes was provided by local emergency responders.

Warning time represents the time available for a person to evacuate once they have received notification from emergency staff. Warning time is the residual of time required to initiate warning and the flood travel time.

An attempt is made to quantify the benefit of an early warning system to the flood areas below Middle Creek dam by evaluating the various warning component times with and without an early warning system (Table 4). Decision time and response time are estimated from information gathered in meetings held with Gallatin County Emergency Response staff the week of November 5, 2007.

Table 4. Estimated Time Required to Initiate Warning

Warning Initiation Components	**Early Warning System (Elapsed Time after Dam Failure)**	
	With	**Without**
Notification Time	1-5 minutes	45-90 minutes (15-60 minutes after water reaches canyon mouth)
Decision Time	1-5 minutes	5-15 minutes
Response Time (to first household at canyon mouth)	8 minutes	8 minutes
Time required for initial warning (cumulative time)	10-18 minutes	58-113 minutes

Warning time is computed for various locations downstream of the dam. This information is used to delineate areas where an early warning system may provide enough advance warning to effectively evacuate people (Table 5).

Table 5. Warning Time Available with an Early Warning System

Population Area along Hyalite Creek	**Time Required to Initiate Warning**	**Flood Travel Time**	**Warning Time**	**Benefit**
Langohr Springs Campground	10-18 minutes	15 minutes	(-)3-5 minutes	No
Canyon Mouth	10-18 minutes	30 minutes	12-20 minutes	Yes
Four Corners	10-18 minutes	120 minutes	102-110 minutes	Yes
Interstate 90 East of Belgrade	10-18 minutes	258 minutes	240-248 minutes	Some
Interstate 90 West of Belgrade	10-18 minutes	414 minutes	396-386 minutes	Some

The area immediately below the dam to the canyon mouth has such short flood travel times that an early warning system provides little or no advance warning to safely evacuate persons in this reach.

People living at the canyon mouth can expect between 12 and 20 minutes of time with which to evacuate. It is conceivable that persons with as little as 12 minutes can remove themselves from the inundation area.

The time available to evacuate increases with distance downstream of the canyon mouth. Those people living in Four Corners can expect approximately 100 minutes of evacuation time.

The entire region from the Canyon Mouth to Logan would benefit from an early warning system. We recognize that in emergency response, every extra minute is helpful in reducing fatalities and property damage. For example, the warning system may provide the extra time needed to evacuate non-ambulatory citizens in downstream locations such as Belgrade, Four Corners and beyond. The degree of benefit, however, varies as the warning time provided by an early warning system becomes a smaller percentage of the total warning time available as the flood progresses downstream. This fact is illustrated by the following conceptual estimates.

At the Canyon Mouth, an early warning system would provide between 12 to 20 minutes of warning time. Without and early warning system these people would have 0 minutes of warning time. An early warning system has a high degree of benefit for these people.

Just east of Belgrade, an early warning system would provide between 240 and 248 minutes of warning time. Without an early warning system, people living east of Belgrade would have between 145 and 200 minutes of warning time. Although beneficial, the degree of benefit is not as high as it is for persons living at the Canyon Mouth.

The fact that benefit from an early warning system diminishes with distance downstream is confirmed by the U.S. Bureau of Reclamation. The loss of life from dam failure could range from 3 to 35 percent if the people at risk are located in an area that has less than 15 minutes of warning time. When warning time is greater than 60 minutes, the loss of life is reduced to approximately 0.5 to 6 percent of the population at risk. The first 15 to 60 minutes of advance warning are the most effective at reducing fatality rates (Graham, Table 7). These statistics quantified by Graham support the notion of diminishing consequences with distance downstream from the dam.

Additional warning time, provided by an early warning system, can reduce the loss of life for areas downstream of Four Corners but not as dramatically as it will for areas upstream of Four Corners. Flood depth and severity are greatly reduced downstream from Four Corners as illustrated in the Middle Creek Emergency Action Plan (DNRC, 2007). Fatality rates will generally decrease as flood depth and severity decrease.

The information summarized (Table 5) is represented on a map (Figure 3) to provide a visual depiction of the areas that would most benefit from an early warning system.

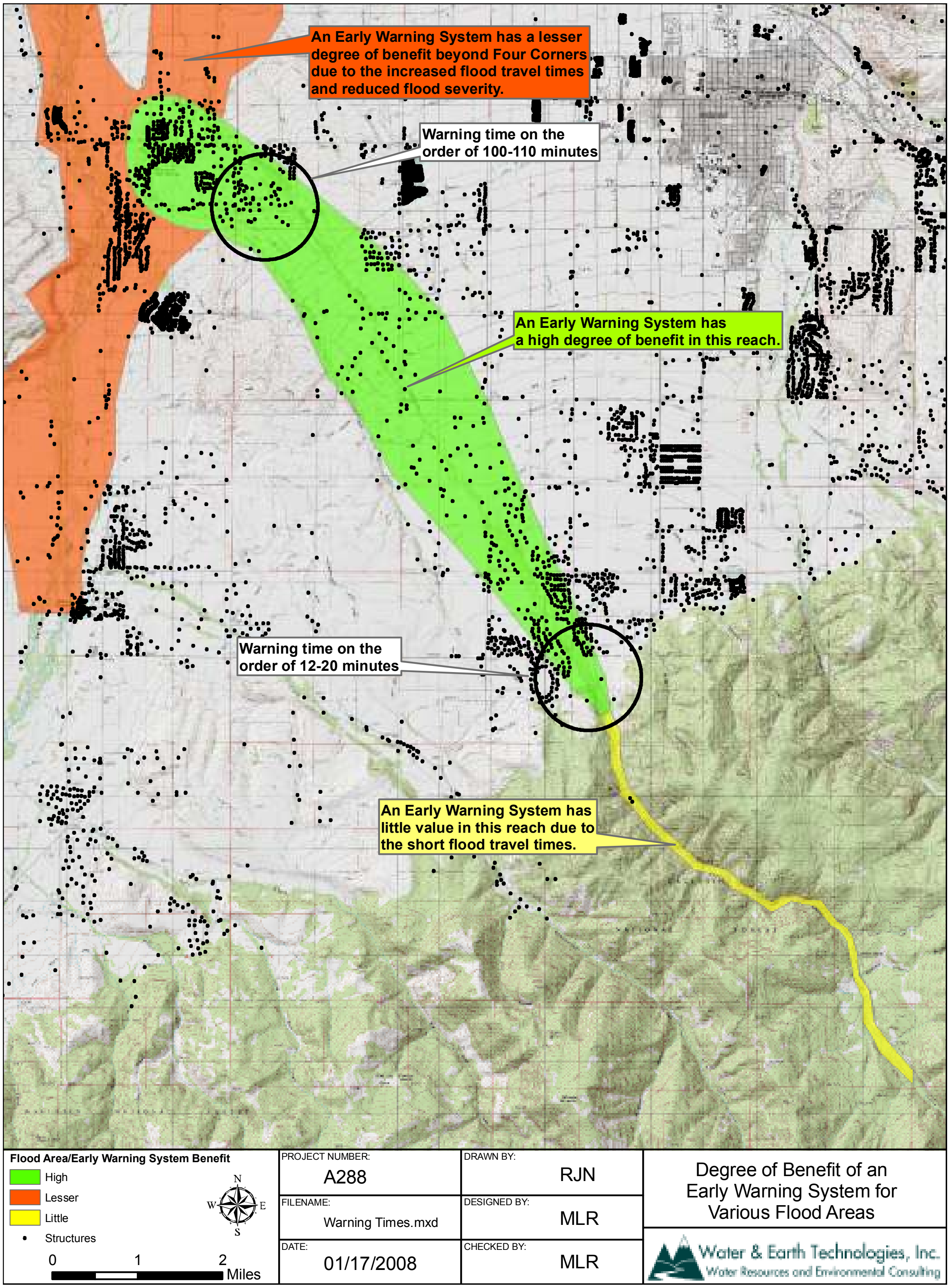

Figure 3. Degree of Benefit of an Early Warning System to Various Flood Areas

Feasibility of an Early Warning System

An early warning system may provide increased evacuation time and reduce the risk to the downstream population due to the following:

1. Temporal considerations identify the area between the canyon mouth and Four Corners as benefiting highly from an early warning system due to the estimated evacuation times provided by such a system (Table 4 and Table 5).
2. Middle Creek Dam is in a remote area and a dam tender is not present on a continuous basis during the high risk (full reservoir) period extending from June through August. This is of particular concern during the night when timely dam failure notifications are less likely to occur because casual observers are not in the area.
3. Cell phone coverage at the dam is marginal. A casual observer or even the dam tender will have a difficult time communicating with anyone from the dam during an emergency.

The technical feasibility of an early warning system is explored in the following sections.

Design Principals Applied by the U.S. Bureau of Reclamation

A face-to-face interview was conducted with Dave Fisher (Manager of Flood Hydrology Group, U.S. Bureau of Reclamation, Denver Federal Center) on October 15, 2007. The purpose of the interview was to solicit information regarding the "standard of care" for early warning systems at earthfill dams owned and operated by Reclamation. The guiding principals obtained from this interview are provided:

1. It is critical to know the water surface elevation in the reservoir. The water elevation should be monitored on a continuous basis using a pressure transducer, shaft encoder or bubbler.
2. It is standard practice to implement redundancy in the monitoring of water surface elevation in the reservoir. Redundancy is developed by installing float trigger switches in the reservoir usually a foot or two below the emergency spillway crest and the embankment crest. It terms of early warning and notification, confidence to issue a warning is always better when confirmation of rising water level is provided from multiple sensors.
3. In terms of static failure, it is critical to understand the flow and changes in flow from the seepage drain system. The total drainage flow should be monitored independently from reservoir outflow/releases. A change in drain flow that is on the order of several gallons per minute is important but is imperceptible if combined with total outflow that may be on the order of tens of cubic feet per second.
4. It is important to know the total reservoir outflow. Stream stage and flow should be monitored on a continuous basis using a pressure transducer, shaft encoder or bubbler at a location downstream of the dam.
5. It is standard practice to implement redundancy in the monitoring of stream water surface elevation downstream of the dam. Redundancy is developed by installing

multiple (typically 3) float trigger switches below the dam or at a downstream stream gage. A cluster of three float switches, each at a different elevation, co-located at the stream gage are used to provide redundant confirmation of rising water levels.

6. It is standard practice to have one weather station at the dam to provide continuous data for rainfall, wind, air temperature and humidity.
7. All data collected by the monitoring network should be transmitted and available for processing in real-time. Reclamation currently employs the real-time, one-way commercial satellite telemetry system available through OneRain, Inc.
8. Reclamation **does not** typically monitor upstream rainfall, snow pack or reservoir inflow. It is assumed that the water level monitoring in the reservoir provides adequate inflow information.
9. Reclamation **does not** employ water quality sensors in their early warning systems. Their experience is that turbidity sensors are too expensive and labor intensive in terms of maintenance, calibration and upkeep.
10. Reclamation **does not** typically employ shear strip sensors to monitor embankment failure due to the high degree of local maintenance required of these sensors. Over the long term, they tend to degrade and require a large amount of maintenance and upkeep.
11. Reclamation **no longer** favors line-of-sight, local radio telemetry systems that require a dedicated base station to be located at the office of a local entity. Reclamation's experience over the past 20 years has lead to the conclusion that local systems require too much attention and dedication from a local sponsor. There is a high probability that the system will not function as required over time due to computer and equipment failure. Reclamation has found that local sponsors tend to lose interest over time in keeping things running as required.
12. Reclamation **does not** favor the deployment of siren-based systems because they are generally not effective, they require aggressive public education campaigns, they are expensive to build, they are extremely expensive to maintain to perpetuity and today's multi-lingual society requires verbal messages in English and Spanish.
13. All alarm and notification aspects of the early warning system must tie directly into the emergency action plan of the dam.
14. All alarm and notification functions must be routed through a facility that has 24 x 7 operations such as an emergency dispatch center.
15. The communication of data/information/text messages is only provided to local emergency responders, water users association, reservoir operators (O&M group) and Reclamation staff. The direct communication with citizens or public is not an aspect of the early warning system. The evacuation of locals must be handled by local emergency response personnel.

Monitoring System Alternatives

This section presents a comprehensive list of monitoring alternatives that may or may not be implemented by the DNRC as part of an early warning system. Later sections of the feasibility study will refine the monitoring alternatives to those with specific application to Middle Creek Dam.

Failure modes are used to describe those conditions that could cause the dam to fail and may include static loading, embankment failure, heavy rains and flooding from upstream, earthquake and landslide. An evaluation of each failure mode is provided in order to develop a comprehensive list of monitoring options specific to each failure mode.

Hydrologic Failure Mode

This mode describes the failure of the dam due to heavy rains and resulting runoff in the upstream watershed. Excessive runoff enters the reservoir and causes the dam to overtop. The large volume of water, in addition to the wave action, can cause the embankment to become unstable and fail.

Although the risk of dam failure during a large hydrologic event is unlikely, the continuous monitoring of upstream hydrologic conditions can provide valuable information related not only to early warning but also to day-to-day reservoir operations.

According to the Middle Creek Dam Manual for Operation and Maintenance, weather conditions are monitored by the dam tender through normal local weather forecasts and the National Weather Service (NWS). If severe flooding is anticipated, a request to the NWS in Great Falls, Montana, is made to provide peak flow, storm duration, runoff duration and total volume flood forecasts into Hyalite Reservoir.

It is advised that the DNRC supplement any runoff forecasts supplied by the NWS with current observations of reservoir level, reservoir outflow, rainfall and other weather information.

Hydrologic Monitoring Alternatives

An automated hydrologic monitoring system could provide valuable data and information related to early warning, dam safety and reservoir operations. Reservoir water surface elevation, outflow and inflow are important to evaluate operations and canyon flows. Additionally, rainfall is useful to ascertain the moisture in the watershed. Air temperature and wind are important to estimate accumulation, ablation and melt of the snow pack. Humidity is useful to estimate the quantity of moisture available in the atmosphere for precipitation.

A hydrologic monitoring network may consist of some combination of the following stations:

1. Two stations to monitor stage and stream flow: one on the East Fork of Hyalite Creek upstream of the reservoir at existing DNRC station No. 41H01000 and the other on the West Fork of Hyalite Creek upstream of the reservoir at existing DNRC station No. 41H01500 (Window Rock Station).
2. A weather station at the dam to provide monitoring of rainfall, air temperature, relative humidity, wind speed and wind direction.

3. A station to provide continuous monitoring of the water surface elevation in the reservoir.
4. One station to monitor continuous stage and stream flow below the dam on Hyalite Creek at the existing DNRC station.

Static Failure Mode

The static failure mode encompasses piping and other seepage related failure modes that may occur during routine loading conditions. Seepage, piping and erosion can cause the embankment to become unstable and ultimately fail.

The DNRC actively monitors the dam to identify the development of a static failure. Inspections of the embankment, spillways and drains are conducted monthly from April through September. In addition, a comprehensive annual inspection is conducted by the State Water Projects Bureau.

The DNRC has installed monitoring devices on and around the embankment which include piezometers, inclinometers and horizontal and vertical control points. The DNRC plans to install an automated instrumentation system at the dam in 2008 to improve its ability to monitor and evaluate embankment performance.

The primary indicator of a developing static failure is increased seepage from the embankment under stable pool elevations. A secondary indicator of a developing static failure is the existence of fine sediments in the seepage water.

In general, instrumentation deployed to monitor embankment conditions can provide days or weeks of warning for the development of a static failure mode. The information collected by a network of embankment sensors can be used to prevent a static failure all together because DNRC staff may be able to change operational aspects of the dam to fix the developing problem.

Static Failure Monitoring Alternatives

A static failure monitoring system could be constructed to provide information on a continuous basis and may include some of the following components:

1. Monitoring of total seepage from the dam using the existing drain system or the construction of a total seepage water collection point.
2. Monitoring of reservoir pool elevation (also recommended under the hydrologic monitoring system).
3. Monitoring of the turbidity of the seepage water (note that turbidity sensors are difficult to deploy and require a high degree of manual maintenance to keep them calibrated and operating correctly over the long term which contributes to their poor reliability).

The data collected on a continuous basis from a static failure monitoring network can be telemetered in real time to a central location where software can receive, process and archive the data. The information can be used to detect a developing threat by identifying rapid changes in piezometric surface, seepage and turbidity relative to the reservoir pool elevation.

Seismic Failure Mode

This mode describes the failure of the dam due to an earthquake. The sequence of events begins with the earthquake, embankment instability, formation of a breach and development of the breach until the entire embankment fails. The embankment may take days to fail or it may fail quickly.

Seismic sensors can detect the presence of ground accelerations. These sensors, however, provide little if any lead-time in advance of a breach. The seismic failure mode has a low probability of early detection due to the fact that the onset of an earthquake is fairly sudden.

A peak acceleration sensor was initially deployed at the dam to record seismic events. The sensor was an Engdal PAR400 peak acceleration sensor which is a passive mechanical seismic sensor. The sensor does not have an interface for electronic data transfer to a data logger. The sensor has not been maintained and was recently found to have been vandalized. This sensor has no current value.

Instead of seismic sensors, many early warning systems employ embankment shear strips and float trigger switches downstream of the dam to detect critical water levels associated with a large instantaneous breach.

Seismic Failure Monitoring Alternatives

A seismic failure monitoring system could be constructed to provide information on a continuous basis and may include some of the following components:

1. Continuous shear strip sensors buried along the entire length of embankment to detect movement of the embankment [Not Recommended].
2. A cluster of float trigger switches at a downstream location to indicate critical water levels associated with an instantaneous breach [Recommended].
3. One or more float trigger switches installed in the reservoir to indicate critical water surface elevations such as: one foot below emergency spillway crest and one foot below embankment crest [Recommended].

Telemetry System Alternatives

The following section presents a comprehensive list of telemetry alternatives that may or may not be implemented as part of an early warning system. Later sections of the feasibility study refine the telemetry alternatives to ones that have specific application to Middle Creek Dam.

Telemetry is a general term that describes the capability for a remote station to communicate with a computer without a physical connection. Telemetry allows access to data collected by the remote stations from the office. In some cases, telemetry can be used to configure the data loggers from the office. Telemetry can provide real-time access to data that would otherwise be available only while visiting the remote station. Telemetry is that aspect of a monitoring system that enables early warning, threat detection and notification.

Several telemetry options are evaluated including GOES satellite, commercial satellite (Argos, Stratos Global, Orbcomm), line-of-sight radio telemetry, cellular and land line.

GOES Satellite

Geostationary Operational Environmental Satellite (GOES) is a federal satellite system that is used by the USGS and NWS to communicate environmental data. The GOES satellites are geostationary, meaning they orbit the same spot above the equator (22,000 miles) at all times. The GOES system provides one-way telemetry, allowing data to be transmitted from remote stations at predetermined time intervals. Communications initiated by the base station to a remote station are not available. All data are transmitted from the remote station to a data center located at Wallops Island, Virginia. Data latency is typically on the order of 1 to 3 hours for standard transmissions and 15 minutes for emergency transmissions. GOES telemetry is not a viable option for systems that require real-time information for early warning.

Commercial Satellite (Argos provided by Campbell Scientific, Inc.)

Campbell Scientific, Inc. offers a satellite transmitter that uses the Argos satellite system. Argos satellites are low-earth, polar-orbiting satellites that provide good coverage for northern latitudes. The Argos system provides one-way communications from the remote station to a central receiving location and regional data processing center. The processing centers are located in Wallops Island, Virginia and Fairbanks, Alaska. As soon as a processing center receives raw data from a ground station, it processes the data and makes the results available to the end user via a network connection. Data latency is on the order of 1 to 20 minutes.

Commercial Satellite (Stratos Global provided by OneRain, Inc.)

OneRain Inc. provides off-site data collection, processing, threat detection and notification using a satellite telemetry infrastructure offered by Stratos Global. The Stratos Global system utilizes a geo-stationary satellite that exists over the equatorial plane. A view of the equatorial plane is required for reliable communications. Middle Creek Dam does have a view of the equatorial sky but locations downstream in Hyalite canyon may not. Line-of-sight to the equatorial sky would have to be resolved during final design.

This Stratos Global system provides one-way communications from remote stations to the central receiving and regional data processing center operated by OneRain Inc. in Colorado.

Once data arrives at the OneRain center in Colorado, it is processed and made available to the end user via the Internet through a web display or through a virtual private network connection. Data latency is on the order of 20 seconds to 5 minutes.

Commercial Satellite (Orbcomm provided by Automata, Inc.)

The Orbcomm system provides two-way communications from a remote station to a central receiving location and regional data processing center. As soon as a processing center receives raw data from a ground station, it processes the data and makes the results available to the end user. Data latency is on the order of 1 to 20 minutes.

The Orbcomm system has a constellation of thirty, non-polar, low earth orbiting satellites that constantly fly overhead. When a satellite is in view, the station can communicate. When a satellite flies out-of-view, the station must wait for another satellite to begin communications again. The satellite coverage in the continental Unites States is good. A view of the equatorial plane is not required because satellites fly overhead.

Line-of-Sight Radio (VHF/UHF Two-way Protocol)

A number of different communication protocols rely on radio frequencies in the VHF and UHF bands. These radios can be used to establish two-way communications between a local base station and the remote monitoring stations. Data can be downloaded and the remote data logger can be re-programmed from the base station. Line-of-sight is typically required between the remote stations and the local base to ensure reliable communications. When line-of-sight is not available, intermediate radio repeaters may be required. A radio license from the FCC is also required.

Data from a remote station is retrieved using line-of-sight radio and Campbell Scientific's LoggerNet software. LoggerNet is used to query data from each station and configure the data logger. Stations are polled in sequential order on a polling cycle set by the user.

Each station is configured to sample data at a set interval. Typically this interval is set to be small so that frequent data readings are available for processing. The latency for data collection using a Campbell Scientific radio telemetry system is estimated (Table 6).

Table 6. Latency Associated with a Typical Two-Way Radio Telemetry System

Data Logger Sampling Interval	LoggerNet Polling Cycle
60 sec – typical interval	1 min – typical time required to collect data from 2 stations

Line-of-Sight Radio (ALERT One-way Protocol)

A second option, using line-of-sight radio, is a one-way protocol called Automated Local Evaluation in Real-Time (ALERT). This protocol is used extensively in the flood warning community to transmit data using a VHF radio transceiver. The primary benefit of a one-way protocol, such as ALERT, is that data collection and transmission occur in real-time. ALERT is the fastest of the communication protocols evaluated and data latency ranges from milliseconds to seconds.

Remote stations are configured to transmit data on both an event and timed basis. Data are received at a central location where it is analyzed by software. A receiving antenna and radio are required at the base location. A one-way protocol does not allow for the base station to query remote stations nor can the data logger be re-programmed from the base station.

Feasibility of Line-of-Sight Radio

In order to assess the feasibility of using VHF radio to communicate data from Middle Creek Dam and Hyalite Canyon to Bozeman, a theoretical radio path study is completed.

Radio telemetry using a VHF frequency (171.100 MHz) does present a feasible option for the early warning system. The following results from the theoretical radio path study confirm that viable radio communications may be developed for the following, redundant, point-to-point links without the use of an intermediate radio repeater:

- Middle Creek Dam to a location in Bozeman such as the dispatch center or to a County radio tower such as High Flat or Nixon Ridge.
- Hyalite Creek stream gage to a County radio tower such as High Flat.

Details and results of the modeling study along with the topography profiles for all modeled links are provided in Appendix A and (Figure 4).

Cellular Phone Service (CDPD Protocol)

The use of cellular data communications requires a connection to be established between two components so that data can be passed between them. Since this type of service is two-way, a connection must be held for the duration of the data transmission.

The standard protocol for cellular data communications is Cellular Digital Packet Data (CDPD) which uses the voice channel available from service providers including Verizon, AT&T and Sprint, etc. CDPD technology sends and receives data over the existing cellular infrastructure. Cellular voice channels are not in use 100 percent of the time and CDPD makes use of the unused channel time to send packets of data.

Use of CDPD requires a modem and an account with a service provider to use the existing system. The service provider maintains and upgrades the cellular infrastructure while the customer is responsible for the modem.

Advantages of cellular technology include: ease of set up, two-way communications and high data transfer rates. Disadvantages of cellular technology include: limited coverage areas, monthly service fees and dropped connections during peak hours.

Cellular technology is not a feasible option because voice channels become saturated during emergencies. The increased use of cell phones by citizens during an extreme event (earthquake, flood, etc.) reduces the available bandwidth and the potential for a data connection to be dropped is high. Also, the cellular coverage area in Hyalite Canyon and at Middle Creek Dam is limited.

Land Line Telephone Service

A telephone modem located at a remote monitoring station connects to the Public Switched Telephone Network (PSTN) through a standard twisted pair phone cable connected to a phone jack. This modem is used to communicate data from the remote station to a base location which establishes a connection when data are required. The connection is two-way.

Advantages of telephone technology include: ease of set up, two-way communications, no antenna required and the technology is well established. Disadvantages include the fact that a direct, twisted pair telephone cable must be installed between the base station and the remote stations. The telephone service has an associated monthly service fee.

Telephone technology is not a feasible option for an early warning system because the installation cost of twisted-pair cable is prohibitive relative to other technologies. Also, buried cable can be severed during an earthquake or landslide.

A comparison of the telemetry alternatives investigated is presented (Table 7).

An important aspect, when evaluating telemetry systems for use in mission-critical early warning systems, is their reliability during an emergency. Of the telemetry options identified (Table 7); VHF radio is the most reliable. Cellular and land-lines are the least reliable. All of the satellite telemetry options route data through a central data processing center and then pass the data back to the user via the Internet (virtual private network or TCP-IP connection). The Internet is a great way to move data from place to place on a national scale, but it has a number of intermediate links that can fail during an emergency. The VHF radio options do not have an intermediate processing link. They transfer data directly from the remote field station to a local location where they can be used for threat detection and alarm/notification.

Of the satellite options presented, the Stratos Global satellite system offered by OneRain is the best due to the small data latency. Information collected from the BOR (Interview with Dave Fisher, October 15, 2007) confirmed the timeliness and reliability of data transmitted using the Stratos Global infrastructure. The best telemetry options are VHF radio using the ALERT protocol and Stratos Global Satellite, due to their latency and reliability characteristics. These telemetry options are explored further in the development of the preliminary design.

Table 7. Comparison of Telemetry Options

Telemetry	Communications	Latency	Data Delivery	Transmission Limitations	Cost	Requirements
GOES Satellite	One-way	15 minutes to 3 hours	Internet from central data processing center in Virginia	Western hemisphere with view of equatorial sky, transmission from canyons may be limited	Free	Formal permission from NESDIS is required
Argos Satellite	One-way	10 minutes, worst case 1 hour	Internet from central data processing center in Virginia	Unlimited, satellites pass overhead	Monthly fee	Permission from Service Argos is required
Orbcomm Satellite	One-way	10 minutes, worst case 1 hour	Internet from central data processing center in Virginia	Unlimited, satellites pass overhead	Monthly fee	Service contract with Automata, Inc.
Stratos Satellite	One-way	20 seconds, worst case 5 minutes	Internet from central data processing center in Colorado	Must have view of equatorial sky, transmission from canyons may be limited	Monthly fee	Service contract with OneRain, Inc.
VHF/UHF Radio	Two-way	1 minute*	Direct to local base (may not require radio repeater)	25 miles, line-of-sight	Free	FCC radio license required
ALERT Radio	One-way	seconds	Direct to local base (may not require radio repeater)	40 miles, direct line-of-sight not required	Free	FCC radio license required
Cellular/Land-line Phone	Two-way	1 minute*	Direct to local base	Limitations in cell coverage area and installation of land-lines	Monthly fee	Service contract with provider

* - The latency associated with VHF/UHF radio and cellular/landline phone are on the order of 1 minute to query information from two stations. Because these telemetry options are based upon two-way communications, time is required to make a connection and to establish the "hand-shaking" between the polling location and the remote station. Once the connection is established and the "hand-shaking" is complete, the polling location must request data since its last connection. Data is transferred and confirmed and the connection is terminated. The same process is then followed to query data from the second station. This process can take as long as 30 seconds per station which translates to 1 minute to query data from two stations.

Existing Emergency Response and Public Notification

For completeness, we are including here a summary of the existing plans and procedures for emergency response to a dam failure and notification to the public in the event of a dam failure.

Response Plans

The success of an early warning system relies on the decision making and actions taken to protect lives and property. A thorough and well thought out response plan is essential to these actions. The best management practice is to develop well-conceived, organized and comprehensive response plans. These plans:

- Assign responsibility to individuals for actions that must be taken.
- Set forth lines of authority and describe how actions will be coordinated.
- Describe how people and property will be protected.
- Identify the personnel, equipment, facilities, supplies, and other resources available.

Middle Creek (Hyalite Dam) Emergency Action Plan

The DNRC maintains an emergency action plan (EAP) for Middle Creek Dam which identifies the lines of communication between state and local officials. The Middle Creek (Hyalite) Dam Emergency Action Plan is invoked under either of two conditions, described as follows:

1. Failure of the dam has occurred or seems imminent – [Emergency Condition].
2. A potentially hazardous situation is developing – [Unusual Occurrence].

The assessment of either condition is currently the responsibility of the DNRC and the State Water Projects Bureau through their regular inspection process or the dam tender through visual observations made while he is on-site. If failure of the dam is imminent or has occurred, notification is first made to the Gallatin County Sheriff's dispatch center. Next, the State Water Projects Bureau is notified and third, the Gallatin County DES. This notification sequence is triggered by the observance of an "emergency condition." If a potentially hazardous situation is developing, notification is first made to the State Water Projects Bureau and to the DNRC supervisor of the rehabilitation section. The State Water Projects Bureau personnel will investigate the unusual occurrence and then decide on further action. If the developing situation is critical, the Gallatin County Sheriff's dispatch center is notified, which in turn notifies the Gallatin County DES. In either scenario, it is the Gallatin County Sheriff's Office that will handle public notification and evacuation. For completeness, we include below a summary of existing emergency response plans and public notification procedures.

The Federal Emergency Management Agency (FEMA) has guidance for development of dam emergency action plans. Suggested elements of an emergency action plan are shown in (Table 8). In column 3, we identify those items that exist in the Hyalite Dam EAP.

Table 8. FEMA Suggested Emergency Action Plan Components

Element	Description	In Hyalite Dam EAP?
Notification Flowchart	Shows who is to be notified, by whom, and in what priority.	Yes. Two notification charts are included. The emergency condition notification flowchart is shown on page iii) and the unusual occurrence flowchart is included on page. v.
Emergency Detection, Evaluation, Classification	These are procedures for reliable and timely classification of an emergency situation.	Yes. This information is included on page 3, 9-16, and 25-26.
Responsibilities	A determination of responsibility for EAP-related tasks must be made during the development of the plan and must be documented in the plan	Yes. Dam operator responsibilities are included on page 4. State Water Project Bureau responsibilities are described on pages 5-7.
Preparedness	This identifies action that will moderate or alleviate the effects of a dam failure or operational spillway release and facilitate responses. These are actions taken before any emergency	Yes. This is included in Appendix G of the EAP.
Inundation Maps	Inundation maps should show areas that will be flooded as a result of dam failure. These maps are used both by dam owner and emergency officials to facilitate notification and evacuation in areas at risk. These maps greatly facilitate notification by graphically displaying flooded areas and showing travel times for wave front and flood peaks at critical locations.	Yes. Inundation maps are included in Appendix C.
Appendices	Appendices contain information to support and supplements material used in development of plan.	Yes. Appendices include the following: Project description, Dam Breach Analysis; Inundation Maps; Project Area Maps; Plan Documentation; Training; Dam Safety Problems; EAP Distribution List.

Gallatin County Emergency Operations Plan

According to Gallatin County's Emergency Management Deputy Coordinator, the County's Emergency Operations Plan (EOP) is undergoing revision. The existing plan contains the following components:

I. Emergency Coordination Plan
II. Continuity of Government Plan
III. EOC Operational Plan
IV. Donations Management Plan
V. Resource List
VI. Persons with Special Needs
VII. Transportation Plan
VIII. Multiple Patient Incident Plan
IX. Recovery Plan
X. Facilities
XI. Fire
XII. Hazardous Materials Plan
XIII. Health Department Plan
XIV. WMD Plan
XV. MSU CERT Plan
XVI. MOU's & Interlocal Agreements
XVII. Hazard Mitigation Plan
XVIII. MSU Emergency Response Plan
XIX. Hospital/ ChemPak Plan
XX. Sheltering/ Mass Care
XXI. Point of Distribution
XXII. GIS Support
XXIII. Public Information
XXIV. Logistical Support
XXV. Volunteer Organizations Active in Disaster
XXVI. School Plans

Fire Departments Operations Plans

We were provided with a copy of the Sourdough and Rae Fire Departments Operations Plans for Community Wildfire Protection for fire incidents. This plan provides information that is also relevant to response to other hazards, such as dam failure. We presume the other fire departments have similar written plans.

Best Management Practices for Response and Recovery Plans

Based on FEMA and U.S. Army Corps of Engineers guidance and on our experience with other successful warning systems, we suggest the response and recovery plans should contain information identified (Table 9). A description of each plan element is included (Table 10). The County should review their plans to ensure these plan elements are included, whether in the County EOP or in other plan documents.

Table 9. Best Management Practice for Flood Response Plan Components

Component	Plan Element
Evacuation and mass-care	Flood search and rescue
	Emergency shelter locations
	Evacuation routes
	Traffic control measures
	Transportation assistance
Temporary-protection	Temporary floodproofing
	Water removal (plans for pumping and other similar actions)
	Surveillance
Vital services maintenance	Electrical power
	Water treatment and supply
	Wastewater collection and treatment
	Transportation
	Health services
	Government
	Volunteer resource management
Public information	Immediate/short-term public information
Post-flood recovery	Human health and welfare protection
	Shelter recovery plan
	Business and government recovery
	Utility restoration
	Clean up
	Financial recovery

Table 10. Description of Plan Elements

Plan element	Description
Flood search and rescue	The evacuation and mass-care plan must ensure the evacuation and proper relocation of all people at risk from flooding. Some individuals at risk may be unaware of the flood hazard (particularly shut-ins or the elderly) and others may choose to ignore the evacuation order. Thus, the evacuation plan must identify those neighborhoods where search and rescue efforts may be needed and it must provide for ground and aerial surveys to determine if rescues are required. The flood search and rescue element of the evacuation plan must also include the following: • Use of flood vulnerability information to identify the areas and facilities where search and rescue should be conducted. The plan also should establish a priority for these operations. • Involvement of local fire and law enforcement personnel to provide assistance in search and rescue operations and appropriate contact information. • Communication and coordination between multiple agencies or departments. • Guidelines for requesting outside assistance for search and rescue operations and appropriate contact information. The evacuation plan does not need to include specific search and rescue procedures, which are the responsibility of the local fire or law enforcement agencies responsible for search and rescue. The evacuation plan should either identify the storage locations and users of search and rescue equipment or identify the agencies and officials who are responsible for the equipment. Further, the plan should be structured to provide adequate information to fire and police commanders to enable them to make informed decisions about the necessary equipment.

Plan element	Description
Emergency shelter locations	The initial goal when evacuating people is to protect them from hazards caused by flooding. The initial action taken is to bring them to a safe location and provide temporary shelter, food and medical care, if needed. Evacuation areas must be: • Safe from flooding and other hazards. • Easily identified by the public. • Accessible by following the evacuation directive (without crossing hazardous low water crossings). • Suitable for use during the duration of flooding and beyond. Specific evacuation locations must be specified so that essentual information can be provided to the public when an evacuation is necessary. For example, a plan might stipulate that “evacuees from the Happy Trails Mobile Home Park should move to the Albert Einstein Elementary School,” rather than simply stating that “residents of low-lying areas should move to higher ground.” A vulnerability analysis can provide useful information for finding appropriate evacuation sites. The evacuation plan must specify: • How and when shelters will be opened and closed. • Necessary supplies, equipment and services. • Allocation of space for shelter functions. • Provision of temporary assistance and information on long-term recovery aid. Long-term shelters may be needed for people who cannot return to their homes for various reasons. Long-term evacuation sites may require kitchens, water supply stations, first-aid stations, hygiene facilities, counseling, disaster information sources and communication services.
Evacuation routes	Evacuation routes must be defined for all areas susceptible to flooding. Evacuation routes must be: • Safe from flooding during the expected time of evacuation. • Passable in all weather. • Adequate to handle expected traffic. Evacuation route decisions should be based on the likelihood of flooding along various routes. Secondary routes should also be determined in case the primary route becomes inundated or otherwise impassable.

Plan element	Description
Traffic control measures	The evacuation plan must consider the increased traffic along established evacuation routes as well as stopping traffic from moving into flooded or potentially flooded areas or flooded low water crossings. The evacuation plan should include the following: • Metering entry for outbound routes. • Maintaining appropriate traffic flow, including dealing with breakdowns and accidents. • Controlling the perimeter on inbound routes and facilitating access to evacuation areas for transportation and vehicles. • Preventing access to damaged areas, roadways and bridges. Law enforcement officials have procedures for providing this traffic control but the evacuation plan should identify routes where such control will be necessary.
Transportation assistance	The plan should provide for evacuating residents of hospitals, nursing homes, retirement homes and care facilities. It should also include information for the public regarding: • How to obtain transportation assistance. • What to take or not take to the shelter, including options available for companion animals. • Where pick-up points are located for those who need transportation.
Temporary floodproofing	The temporary protection plan should identify the following: • Locations of critical facilities at which temporary floodproofing and flood barriers will be installed. For example, if flood barriers are to be installed at the local post office, that should be noted in the protection plan, along with contact information for the facility manager who is responsible for installing those barriers. • Sources of material for temporary protection. For example, locations should be established for storing sandbags and sand during the flood season, and these should be described in the protection plan. If materials are available from local building supply stores, the locations of those stores should be specified, along with appropriate contact information. • Sources of labor and equipment to install temporary flood barriers. If private contractors are hired to install equipment, the plan should identify those contractors. If local agencies are responsible, the organization of personnel should be described in the temporary protection plan.

Plan element	Description
Water removal	Flow into building basements or seepage into areas otherwise protected by temporary flood barriers may require short-term pumping. Accordingly, the temporary protection plan should anticipate this need and address the following: • Where is pumping likely to be required? • What size and type of pumps are required at each location? • Who has these pumps, where are they stored and who should be contacted to provide them? • What personnel are needed to set up and operate the pumps? • What are the fuel requirements for the pumps, and where is fuel stored?
Surveillance procedures	Assigned personnel should inspect facilities protected by temporary measures to ensure proper performance. The temporary protection plan should identify personnel and equipment to be used and a monitoring schedule. Likewise, the temporary protection plan should include provisions for monitoring permanent drainages and stormwater management features that are not otherwise monitored.
Electrical power	The vital services maintenance plan should identify power facilities that may be affected or damaged by flooding, as well as circumstances in which electrical power to flooded areas may be lost or shut off. It should also include a plan to restore power. Provisions should include inspections and surveillance to locate downed power lines, flooded power vaults, damaged transformers or other damaged equipment that could pose a hazard. For critical locations such as hospitals, public safety facilities and evacuation centers, auxiliary power may be required. The services maintenance plan should identify these facilities and the source of auxiliary power. If portable generators are used, the plan should identify who will provide them, move them to the sites and configure and operate them. If resources are limited, the plan should prioritize the distribution of generators and other available energy sources. The management staff of all critical facilities should be encouraged to develop their own preparedness plans, which can address the potential need for auxiliary power.

Plan element	Description
Water treatment and supply	Flooding can damage water treatment plants and the water supply network. Flooding of water supply facilities (including wells) can contaminate the water supply and produce major health hazards. The response plan should identify water treatment and supply facilities at risk and sources of water to use in an emergency. The plan also should include policies for shutting down and restarting the system. The plan should refer to procedures for: • Using the additional water supplies. Availability of special equipment, such as water trucks, temporary pipelines and new wells should be described in the plan. • Monitoring the safety of all components of the water supply system. • Decontaminating and repairing the water supply system, if contamination occurs.
Wastewater collection and treatment	Even minor flooding can enter the wastewater collection system or treatment facilities and contaminate the floodwaters. The vital services maintenance plan should include or refer to procedures describing the following: • How to identify sites of contamination. • How to monitor the spread of waste in the floodwater. • How to control and clean up contamination. The vital-services maintenance plan should also provide for post-flood evaluation of the wastewater collection and treatment facilities to identify the effects of floodwaters on the system. These effects may include damage by erosion during the flood event and flood damage to lift stations, pumps, screens and control facilities. The response plan should define methods of dealing with sewage and waste during periods when the collection and treatment system is offline. Sources of portable latrines should be identified, along with policies for acquiring them.
Transportation	Timely rehabilitation and repair of damaged roads and bridges is critical to individual residents as well as the local economy. The response plan should provide for identifying damaged routes, assigning priorities to these routes and for notifying and cooperating with the appropriate agencies during the repairs. Following a flood, citizens may have to rely more on public transportation because of water damage to automobiles. This need may be especially intense between evacuation destinations and areas of employment. The response plan should provide for increasing the availability of public transportation. The plan should identify sources of additional transportation services and describe the arrangements that have been made to secure them.

Plan element	Description
Health services	Health service facilities in the community generally have procedures in place for dealing with emergency operations. The vital services maintenance plan should provide for coordination between local government and health services facilities to provide health services to the public during and after a flood. The plan should include the following: • Establishing temporary emergency, public health, environmental health, mental health and mortuary facilities. • Relocating hospitals to temporary facilities under extreme inundation conditions. • Transporting and evacuating the injured. • Properly disposing of the dead. • Controlling disease that may spread as a consequence of the flood. • Requesting aid from other agencies or businesses, especially if major facilities are in flooded areas.
Government	Government services must continue during a flood event. Therefore, the vital-services maintenance plan should include or refer to procedures for: • Identifying facilities at risk of inundation or at risk of loss of power, water or other utilities. The vulnerability assessment can help with this identification. • Identifying sites where agencies or departments may be relocated. The vulnerability assessment can help with this identification. • Specifying how vital records and equipment will be protected from flooding. If relocation is required, the vital services plan should include step-by-step instructions for this relocation, including identification of the relocation site, safe routes to the site and sources of equipment and personnel required for the relocation. • Identifying sources of emergency power and communications available to local government agencies. • Defining specific emergency measures to continue government activities during the first 12 to 24 hours of the emergency.

Plan element	Description
Volunteer resource management	Volunteer manpower, resources and equipment will become available during and after a flood-related emergency. Notwithstanding the benefits that these resources can provide, if not employed in a controlled manner, they can aggravate the problem. Therefore, the vital services maintenance portion of the flood response plan should provide for the following: • Determining which offers of help will be accepted. • Cataloging available resources. • Establishing and administering holding areas for resources physically available but not immediately needed. • Directing resources to areas of need.
Public information	The public must be informed of the impending hazard, provided with information about appropriate response, informed of the actions taken to protect them and their property and kept current regarding the state of the emergency. The public information plan should provide for: • Who will be notified. • Who will disseminate emergency information (i.e., which agency is responsible for notifying the public). • How the information will be disseminated. • What conditions will "trigger" notification to begin. The plan must specify water level or other environmental thresholds at which public notification will be necessary. • What the content of the information will be. This should be developed in advance as much as possible. A public flood preparedness education program, which is conducted year-round, is also a vital element in a flood warning and response system.
Human health and welfare protection	Health and welfare hazards exist following a flood. Floodwaters may contain untreated sewage, dead animals and hazardous materials. Structures and transportation facilities may be damaged and unsafe for use. The post-flood recovery plan should describe the following: • Provision of safe drinking water. • Restoration of sewage treatment facilities. • Removal of hazardous materials from areas that were flooded. It should also provide for post-flood monitoring of water quality and sanitary conditions as well as continued dissemination of information to the public regarding health and safety issues.

Plan element	Description
Building safety	Buildings must be checked for safety before residents and businesses can return to their properties. Local fire and building departments may inspect structures after a flood and the post-flood recovery plan should reference those procedures. In addition, the plan should include provide for the following: • Identifying buildings and structures that may threaten public safety. • Designating buildings and structures that may not be occupied safely. • Condemning buildings and structures. • Organizing long-term housing and other recovery operations for people who cannot return to their homes. In the case of widespread flooding, additional resources beyond those normally available for fire and building safety inspection may be required and the post-flood recovery plan must describe how these resources will be provided.
Business and government recovery	The post-flood recovery plan should provide for re-establishing business and government operations as soon as possible after the flood emergency is over. Local businesses should take responsibility for some of this planning. Damages to utilities and transportation links can also have an adverse impact on the ability of business and government to restore normal operations. The post-flood recovery plan should identify these indirect impacts and, to the extent possible, identify measures and temporary solutions.
Utility restoration	Loss of power, water treatment and supply and wastewater collection and treatment can create critical problems for emergency response, for health and welfare and for government and business operations. The post-flood recovery plan should provide for coordination of agency efforts and should ensure that information and support are provided as appropriate. The plan should include the following: • Identifying utilities that are out of service. • Identifying residences and businesses affected by the outage. • Assisting and contacting companies and agencies responsible for restoring the utilities.
Clean up	Following a flood, arrangements must be made for orderly clean up and removal of debris from public areas, private residences, and businesses. The post-flood recovery plan should provide for: • Pick up and removal of debris and damaged materials. • Identification of areas for disposal of debris and damaged materials. • Identification of personnel and equipment available for clean up of public areas, as well as sources of outside assistance.

Plan element	Description
Financial recovery	The post-flood recovery plan must include arrangements for financial assistance to individuals and businesses affected by the flood. The plan should provide information regarding access to: • Temporary housing assistance. • Low interest loans to individuals and businesses. • Individual and family grants. • Public assistance from state and local governments, special districts and private nonprofit agencies. The post-flood recovery plan should anticipate participation of the Federal Emergency Management Agency (FEMA) and American Red Cross and should identify procedures for requesting and administering this aid.

Public Notification for Middle Creek Early Warning System

As threats are recognized, appropriate warnings are disseminated to emergency personnel and from emergency personnel to the public.

Existing methods for contacting the public include the following:

Gallatin County Emergency Preparedness Notification System. The County is currently implementing the Emergency Preparedness Network System (EPNS). EPNS is designed to notify rapidly residents in an affected area of an emergency by sending a prerecorded message through the telephone system. EPNS uses the 9-1-1 database to extract phone numbers of residents in a selected area. Areas can be selected “drawing” a circle around residents on a map or areas can be premapped.

The EPNS is a service provided by Qwest and Intrado. According to Ben Hess, Director of Gallatin County 9-1-1, a test of the system was conducted successfully on November 28, 2007. The test included a broad spectrum of areas within the County.

Since the 9-1-1 database does not include cell phones, calls will be placed to land-line telephones only. The County is looking into ways to add cell phone numbers to EPNS but that capability is not part of the current implementation.

Emergency Alert System. In the State of Montana, the Emergency Alert System (EAS) can be activated by NWS personnel only. Designated County personnel can contact NWS to ask for EAS activation and can provide a message for dissemination over EAS. NWS authenticates the message and activates the EAS system. NOAA Weather Radios will automatically alarm when EAS is activated. Broadcast media will receive and broadcast the message over television and radio networks.

Phone tree. Residents of the Sourdough Fire District have formed a phone tree, called Neighborhood Network, for notifying their neighborhood in emergencies. This has worked well for them during past events (fires). The Neighborhood Network is activated at the request of the local fire department.

Neighborhoods involved include the following:

- Forest Creek
- Hodgeman Canyon
- Hyalite Foothills
- Hyalite Meadow
- Lazy TH:
- Mystic Heights
- Triple Tree Ranch (Sourdough and Rae FD, 2007)

2-way radio. There are 6 families who live at the base of the canyon who carry 2-way radios for communication with their local fire district and each other in the event of an emergency. These families have been involved in Community Emergency Response Team (CERT) training for 5 years and continue to meet monthly to practice emergency/disaster skills.

Personal, door-to-door notification. During interviews with emergency personnel, we learned that door to door notification is used to alert residents. Fire department personnel interviewed estimate that 8 minutes is required per household for door-to-door notification.

Roadway signs. Montana DOT has 2 variable message signs in place on major roadways. These can be used to provide messages that roads are closed. The County also has 3 Highway Advisory Radio Portable roadway signs.

Early Warning System Preliminary Design

Two preliminary designs for an early warning system at Middle Creek Dam have been developed. Each design presents a single architecture in terms of a monitoring network, telemetry system, data processing mechanism and threat detection. The preliminary design includes components that may be used at other DNRC dams but is specifically developed to address those issues relative to Middle Creek Dam.

The preliminary design is influenced by "guiding principals" obtained from the U.S. Bureau of Reclamation which has more than 30 years of direct experience in the design, implementation and maintenance of early warning systems for dams across the U.S.

Dam Failure Monitoring Components

The preliminary design to detect dam failure at Middle Creek Dam includes two monitoring stations that function independently to detect and confirm dam failure. The monitoring stations include:

1. A station at the dam to monitor critical water levels in the creek immediately below the dam. This station will include a cluster of three float trigger switches installed at different elevations. This station will also include a float trigger switch installed just below the emergency spillway to detect critical water elevation in the reservoir.
2. A station approximately one mile below the dam at the existing DNRC stream gage to monitor water level in Hyalite Creek. This station will include a cluster of three float trigger switches to detect critical water levels and a continuous water level sensor such as a pressure transducer or bubbler gage. The data from this station would most likely serve as confirmation to a warning initiated from the upper dam station. The flood travel time is accounted for in the decision time component. Warning could be initiated from either the station at the dam, the stream station or from some combination of data from both stations that is processed through some logical structure. The final warning criteria must be determined in the final design.

The following stations were identified in the monitoring alternatives but are not included in the preliminary design:

1. Reservoir inflow monitoring at two locations: one on the East Fork of Hyalite Creek upstream of the reservoir at existing DNRC station No. 41H01000 and the other on the West Fork of Hyalite Creek upstream of the reservoir at existing DNRC station No. 41H01500 (Window Rock Station). These stations are not recommended because Middle Creek Dam can safely pass the PMF.
2. Reservoir surface elevation monitoring. This sensor is not recommended as part of the early warning system because it will be installed as part of the DNRC planned equipment upgrade. Having a sensor in the reservoir that monitors water surface elevation will allow the DNRC to evaluate the current content and remaining capacity of the reservoir.

3. Monitoring of embankment movement using continuous shear strip sensors that are buried along the entire length of embankment. These sensors are difficult to maintain over the long term. Their reliability decreases markedly with age and they are thus not considered a reliable option.
4. Monitoring of the turbidity of the seepage water. These sensors are not recommended due to the high cost of maintenance and upkeep. The continuous monitoring of drain flows obtained through the DNRC's planned equipment upgrade will provide an assessment of piping and seepage issues if they develop.

Telemetry System Components

Two telemetry system alternatives are identified (Table 7) that can best meet the requirements of the early warning system. These alternatives are described further below and summarized in two drawings (Drawing 1 and Drawing 2).

Preliminary Design Option 1 – OneRain StormLink System

The first design includes the transmission of data from the monitoring network in near real-time using commercial satellite telemetry. The design is based upon the SDX satellite telemetry service (StormLink) offered by OneRain, Inc. which uses the Stratos Global geo-stationary satellite. This is the same service used by Reclamation and BIA for their early warning systems operating at federal dams.

A satellite transmitter is located at each station. Data are transmitted using L-band radios via a secure connection on the Stratos Global satellite system. Data are received, processed, validated and archived into OneRain's secure 24x7 enterprise database at their redundant regional processing centers located in Denver, Colorado. Data can be accessed by DNRC and County staff through a standard web-browser from office workstations or from web-enabled devices such as smart cell phones.

Preliminary Design Option 2 – VHF Radio Using the ALERT Protocol

The second design option includes transmission of data from the monitoring network in real-time using VHF radio telemetry and the ALERT protocol. The design is based upon a well established, real-time telemetry solution utilized in the flood warning industry. The open source protocol allows for multiple vendors including Campbell Scientific, Inc., HydroLynx Systems, Inc. and High Sierra Electronics, Inc. to supply equipment.

A radio transceiver is located at each station that will interface directly to the local data logger. Data are transmitted using a VHF frequency in the hydrologic communications band (169.425 MHz to 171.925 MHz). The Federal Government allows use of this band of frequencies to collect meteorologic and hydrologic data to be used in emergency operation planning. A radio license must be obtained from the FCC in order to implement this design.

Data are received by specialized software operated at the County Dispatch Center. Two redundant radio receivers will be established to collect the radio data directly. All data communications and notification functions will be handled by the County using their existing communications infrastructure.

This alternative involves the implementation of multiple local reception points to collect data transmitted from the monitoring station at Middle Creek Dam and from the Hyalite Creek stream gage. Based upon results from the theoretical radio path study, the best reception locations include the county's High Flat radio tower and a location in Bozeman (EOC, Law and Justice Center, or the new dispatch center). The results from the theoretical radio path study should be verified through field testing.

Data signals from Middle Creek Dam and Hyalite Creek will be broadcast using VHF radio. The VHF transmissions will be received simultaneously at High Flat and at the EOC in Bozeman. The High Flat location will be configured with a radio repeater to re-broadcast the signal so that additional redundant receiving locations in the Gallatin Valley can directly receive the information. Once data signals are received, they will be routed to the County Dispatch center using existing County infrastructure (microwave, LAN, WAN, etc.). No part of this system would be outsourced to a private company. All data communications will rely on existing County network components.

Software running at the County Dispatch Center will be used to receive and process the data signals. The software will be integrated into the County's existing Computer Aided Dispatch (CAD) architecture and software.

In order for this option to function reliably, a commitment by a local entity such as Gallatin County Department of Emergency Management to meet the following requirements is necessary:

1. A software application, requiring a dedicated terminal interface must be available at the dispatch center. The software must operate round-the-clock and can never be turned off.
2. An individual should be available to maintain the software and ensure it is running correctly. Updates to the software may periodically be available from the vendor.
3. Any hardware installed at the receiving locations including the radio antenna, lightning protection, radio receiver and analog/serial modem must be actively maintained to ensure proper functionality.
4. All hardware must be connected to fault tolerant power supplies such as a back-up generator so that if the power goes out, the equipment will continue to function.
5. The entire early warning system should be tested once per year.

Operating an early warning system is not a trivial endeavor. It requires dedicated staff to ensure everything is functioning correctly and to conduct periodic tests of the system.

Threat Detection System Components

OneRain Inc. Threat Detection Alternatives

OneRain offers two alternatives for threat detection and notification of emergency response personnel. One option utilizes OneRain's proprietary infrastructure in Colorado.

The second involves the use of a national monitoring center established by the Bureau of Indian Affairs in Ronan, Montana.

Bureau of Indian Affairs, National Monitoring Center

The Bureau of Indian Affairs (BIA) has developed a National Monitoring Center (NMC) operated by the Flathead Reservation in Montana. The NMC supports early warning functions at more than 70 BIA dams in the western United States. The program and command center are operated on a 24 x 7 basis to provide early detection and notification of developing hazards to dam owners and emergency response personnel.

The NMC is built upon the data telemetry and collection infrastructure developed by OneRain Inc. Hydrologic and site-specific dam/reservoir data are transmitted to the OneRain national data collection and processing center located in Colorado. Data are collected using commercial Stratos Global satellite telemetry. A primary database with redundant back-up is used to receive, process and archive all incoming data. Software is used to test the incoming data against threshold conditions (provided by the end user). Once a threat is detected, notification is made to NMC staff. When an alarm condition is received by the NMC dispatch center further notification is provided to critical personnel depending upon the severity of the alarm condition. The notification provided by the NMC is typically made to BIA staff, Reclamation staff and local emergency response personnel. In summary, the OneRain system in Colorado provides notification only to the NMC when alarm conditions are exceeded. The NMC is responsible to provide further notification to local entities.

Extension of the NMC to include Middle Creek Dam is a possible alternative. This option would require a separate contract negotiated with the Flathead Reservation to provide 24x7 threat detection, notification and dispatch services.

OneRain, Inc. Proprietary Infrastructure in Colorado (StormLink)

OneRain provides satellite telemetry hardware to enable remote stations to transmit data to their national data processing center in Denver, Colorado.

Threat detection criteria supplied by the DNRC can be configured at OneRain's data processing center. When a threat is detected, notification via email and text pages are made to critical emergency services staff within Gallatin County and to the DNRC from the OneRain processing center.

A private, off-site data processing facility has the follow advantages:

1. These systems are mature in that they have been tested by federal entities over the past several years. They have staff dedicated round-the-clock to ensure the system functions continuously and they employ fault tolerant network architectures that include redundancy and fail-over.
2. Little or no dedication of a local entity's staff resources or hardware is required. If the Gallatin County dispatch center is used to perform notification, some training will be required of staff to route alarm messages to the proper people. For example, a code/manual is typically developed that allows the dispatcher to quickly identify which persons should receive which alarm messages.

3. These systems operate in near real-time (on the order of minutes) and the latency between an actual dam failure and the receipt of a warning message to the pager of an emergency responder is on the order of minutes.
4. Out sourcing of the data transmission, processing, threat detection, alarm and notification functions may decrease the required technical expertise for operation and maintenance of the system within DNRC and Gallatin County. A private company, such as OneRain, once under contract, is responsible for the reliable and accurate functionality of the early warning system in terms of the telemetry system, data processing and alarm/notification components.

OneRain can perform planned, proactive system maintenance and they can conduct a system-wide test once each year. OneRain can not respond to break-down service requests in an immediate fashion because of their physical distance from Bozeman. It could take OneRain up to two weeks to respond to an emergency repair request.

Preliminary Design Option 1 – OneRain StormLink System

In the preliminary design (Drawing 1), data flows on a continuous basis from the monitoring stations to the OneRain regional data processing facility in Colorado. The data are available via the Internet for display and processing by DNRC staff, the emergency response community and the Water Users Association staff via a standard web browser.

A developing threat will be detected by comparing the real-time data against a set of alarm criteria. These criteria must be established by the DNRC engineering staff and may include if-then-else type logic.

Alarm criteria will be entered and maintained by DNRC staff using the web-based alarm/notification system provided by OneRain. The alarm functionality will run on a 24 x 7 basis at the data processing center in Colorado.

Once an alarm is triggered, the OneRain system will notify the Gallatin County Dispatch Center via email and text pages. OneRain will not provide a landline telephone call from a live person at OneRain to a County dispatcher.

The OneRain system will record additional critical information so that a defendable paper trail is created to show a post event time line that includes the following:

- date/time of detected threat and alarm activation.
- date/time that notification was issued.

Preliminary Design Option 2 – VHF Radio Using the ALERT Protocol

In the second design option (Drawing 2), failure of the dam is detected at one or both of the monitoring stations which will then initiate a data transmission to the County Dispatch Center.

The decision logic should reside at the monitoring locations. It is not desirable for a dispatcher at the EOC or any other individual to interpret or analyze hydrologic information during an emergency. During final design, the logic criteria should be developed so that hydrologic conditions can be evaluated locally at each remote station to determine a dam break condition. The programmable data logger located at each remote monitoring station will then be programmed with the decision logic during construction. The information transmitted from the remote stations should represent a binary condition. Either the condition at Middle Creek Dam is good (not in alarm state) or bad (the dam has failed and we are in alarm state).

Specialized software running at the dispatch center will receive the radio data transmissions and automatically interface to the County's CAD (Computer Aided Dispatch) system to alert dispatchers when an emergency condition is detected.

Once an alarm is triggered, the County's CAD system will record additional critical information so that a paper trail is created to show a post event time line that includes the following:

- date/time of detected threat and alarm activation
- date/time that notification was issued

System Reliability Analysis

Two design options are developed for the early warning system based on different telemetry architectures: 1). OneRain's StormLink system and 2). VHF radio using the ALERT protocol. The options are similar in many respects including the monitoring network. The primary difference between the two options is the telemetry system, the data processing and alarm/notification system.

The following evaluation attempts to assess the reliability of each option through a conceptual fatal flaw analysis. Each option is evaluated in terms of its reliability to complete the primary objective which is to provide early warning in the case of dam failure. Details of the fatal flaw analysis and a comparative summary of the different telemetry options are summarized (Table 11).

Given the preliminary radio path modeling results and the incorporation of the existing County-owned communications infrastructure, the VHF radio telemetry option using the ALERT protocol is determined to have a higher degree of reliability than the OneRain StormLink satellite option (Table 11). The increased level of reliability is partially achieved through the County's commitment to maintain control of the communications infrastructure. The County is committed to maintain and service, at a moment's notice, every aspect of their communication system, including any additional new hardware associated with the early warning system. Additional reliability is achieved through the direct VHF radio links between the monitoring stations and multiple redundant County-owned radio reception locations (High Flat Tower, Nixon Ridge and Dispatch Center in Bozeman).

Table 11. System Reliability Analysis

System Component	Discussion	Reliability Score (1 to 10, 10 is best)	
		OneRain StormLink	ALERT Radio
Sensor/monitoring network	The sensor monitoring network is the same for both options. Redundancy is achieved by using multiple sensors (continuous water level and float trigger switches). Additional redundancy is achieved by developing separate monitoring stations (one at the dam and a second downstream) with independent data loggers and sensors.	9	9
Telemetry network	There is a strong possibility that the VHF radio option will not require an intermediate radio repeater. If so, the reliability of the radio telemetry system will be high because a repeater is considered a single point of failure. The StormLink architecture employs a commercial satellite which is a single point of failure. If the satellite goes down, all communications are lost.	5	9 (without repeater) 5 (with repeater)
Data reception	Both options utilize multiple, redundant receiving locations. The ALERT option uses two radio reception locations, one in Bozeman and a second at High Flat tower. The StormLink network has multiple downlink stations.	10	10
Data flow to processing location	The ALERT option uses the County's existing communications and network architecture to route data from the radio reception locations to the dispatch center. This network is completely developed and maintained by the County and has a high degree of reliability. The StormLink option relies on an Internet-based network connection (X.25, TCP-IP) to move data from the primary ground station to the OneRain processing facility.	5	9
Data processing/alarm detection	The VHF radio option relies on a single application running at the Dispatch Center to process data. The application must function on a 24/7 basis, have automatic power backup and run on a dedicated computer. The application represents a single point of failure. The StormLink option uses multiple base stations at spatially variant facilities (Longmont and Denver) to receive, process and perform alarm functions on the real-time data.	9	5
Notification	The VHF radio option relies on the existing County dispatch notification system which has a high degree of reliability. The StormLink option sends email and text pages using Internet-based tools from base stations in Colorado. Internet notification methods are considered less reliable during an emergency.	5	10
Reliability Score		**43**	**52 (without repeater) 48 (with repeater)**

Notification Process as Related to the Emergency Action Plan

The connection between the early warning system and the evacuation of the population at risk is the Middle Creek (Hyalite) Dam Emergency Action Plan which is invoked under either of two conditions is described as follows:

1. Emergency Condition - Failure of the dam has occurred or seems imminent
2. Unusual Occurrence - A potentially hazardous situation is developing

Presently, these two conditions are assessed by the DNRC through their regular inspection process, by the dam tender or through analysis of monitoring data. It is anticipated that DNRC or WUA staff will conduct inspections twice per week during the 2008 irrigation season.

The early warning system is designed to detect dam failure which is associated with the Emergency Condition in the EAP. The assessment is provided by float triggers at the dam and in Hyalite Creek below the dam.

For example, if a water level sensor detects a stage value of 10 feet and the float trigger switch confirms a critical level of 10 feet, then an alarm will be triggered and sent to the County Dispatch Center. The logic employed to detect the emergency condition should require that two or three of the four sensors at the downstream gage detect the same reading. This level of redundancy should be incorporated into all alarm logic to avoid false alarms.

Once the Gallatin County Sheriff's dispatch center receives the alarm condition it would notify appropriate emergency response staff including the Sourdough/Rae Fire Department, DNRC staff, State Water Projects Bureau staff and the Gallatin County DES personnel. It is the goal of the early warning system to develop additional time so that local agencies responsible to mitigate damages have more time to complete their mission. It is not the purpose of the early warning system to communicate directly with local citizens.

Public Notification

Once County dispatch and response personnel have received messages that a threat condition exists at Middle Creek Dam, the County will notify citizens following procedures outlined in their response documents.

We included earlier in this report existing procedures used for public notification. Here we expand on what criteria are required for successful public notification. We include a list of feasible notification methods (some of which are already in place) and provide our assessment of the feasibility of each for implementation. We also include a summary of the opinions and desires for public notification that we identified from interview with key stakeholders. We include examples of how public notification is managed in other dam early warning system and flood early warning systems.

Finally, we identify items that can be implemented at low cost and items that may enhance public response once they are notified.

Criteria for Successful Public Notification

Successful notification requires that (1) useful messages are sent in a timely manner, (2) messages are received by the intended audience and (3) messages are understood. To accomplish this, the following tasks must be accomplished:

- A notification plan must be developed that documents who will receive messages, when, and by what mechanism.
- Messages must be developed so that recipients can understand, believe and personalize the information being disseminated.
- Multiple notification methods must be in place for disseminating the message to intended audiences.

These are described below.

Notification Plan

This plan is a set of detailed, specific instructions about who is to be notified, how, at what threat or warning level and by what method. Instructions in the plan can be written as:

IF <*threat threshold*> THEN notify <*recipients*> using <*method*> with <*message*>

A simplified example follows: IF *outflow from dam is greater than 10 feet*, THEN notify *Kandy Rose* using *fire department issued pager 406-581-xxxx* with message *"begin phone tree."*

Notification plans must be continually maintained and updated on a regular basis as contact information for people or agencies change.

Warning Message

Message content will vary depending on the recipients of the message. Regardless of the audience, the message should be clear, specific, consistent, certain and accurate to the extent possible (Sorensen 2000). In addition, message templates should be developed in advance that provide basic information, with real-time information inserted manually (by dispatcher) or automatically (by base station software). (Warning message can be abbreviated for emergency personnel but should not be for the public.) Warning messages sent to the County Dispatch by either of the preliminary design options should include the elements listed below (Table 12).

Table 12. Warning Message Content**

Element	Description
Source of the warning	The message should include the sources of information. This helps establish credibility of the warning.
Point of contact	The message should include a phone number or other contact information.
Time and duration of warning	To avoid confusion, the message should provide the time and date of issuance of the message, and state when the warning will expire.
Location of impending risk	The message should be specific and use language that emergency personnel and the public will understand. It should identify the following:

	• Primary area of impact. This is the geographic location of the expected event and the area of greatest expected damage. • Secondary area of impact. This is the geographical area that can expect to sustain indirect damage from the event or that will be impacted by victims of the event.
Nature of flood	The message should describe the nature of the flood in sufficient detail that emergency personnel and/or the public will understand the risk. Thus, they will be able to decide what actions to take and which of their current guidelines to follow. Depth, elevation, velocity and other characteristics of the expected flooding should be included in the message, to the extent that this information is available. Depending on the method of message transmission, graphics of the impacted area may be included. The probability of the event occurring should be relayed in the message, if such information can be determined.
Time available	If the information permits, the message should state the lead time—the time available to engage in protective action.
Specific guidance	The message should provide guidance on what actions to take.
End of message delimiter	Identifying the end of the message will avoid confusion, especially if communications may be disrupted.

** - Modified from Mileti and Sorensen 1990

Notification Methods

A number of formal methods may be used by officials or emergency personnel to disseminate information to the public. These include the following:

- Emergency Alert System
- Personal contact by emergency officials
- Commercial broadcast radio
- Two-way radio
- Television
- Telephone, dispatcher-dialed
- Telephone, automated dialing system
- Citizen phone tree
- Sirens
- Internet Web site
- E-mail
- Paging
- Desktop data delivery
- Roadway signs

Additional information on these methods is provided (Table 13). Our assessment of how each might work in Gallatin County is included in column 3. Like other components of an early warning system, notification methods must be redundant. There is no one method to reach everyone at risk. Notification methods implemented must ultimately be technologically and economically appropriate for implementation and for operation, maintenance, repair and rehabilitation.

In addition, informal notification plays an important role in the warning dissemination in most emergencies. For example, individuals may call or contact in person friends, family, neighbors, colleagues and so on. Likewise, individuals can be alerted to emergency conditions based on environmental cues, such as seeing or hearing water approaching.

Table 13. Common Methods for Disseminating Warnings to the Public

Notification Method	Description	Assessment
Emergency Alert System (EAS)	The EAS is a national public warning system that requires broadcasters, cable television systems, wireless cable systems, satellite digital audio radio service (SDARS) providers and direct broadcast satellite (DBS) service providers to have the capability to address the public during a national emergency. The system may also be used by state and local authorities to deliver important emergency information such as AMBER alerts and weather information targeted to a specific area (FCC 2007). EAS messages can be received by a number of message broadcast devices including: • Television • Radio • NOAA Weather Radio (NWR). NWR provides continuous broadcasts of the latest weather and hydrologic information. During severe weather, NWS forecasters can interrupt the routine weather broadcasts and substitute special warning messages. NWS staff can activate specially designed receivers that will warn the listener of impending hazards using a special tone alert. This tone alert will activate the radio if it is in stand-by mode. NWR will also sound EAS warnings. • In home tone-alert radio receivers. Radio receivers such as Federal Signal Corporation's Informer can be programmed to decode EAS alerts. Upon receiving an alert, they broadcast loud beeps and can be adapted for the hearing impaired. These tone-alert radio receivers are suitable for residences, schools and other indoor settings.	EAS alerts can quickly reach large groups of people by multiple paths. However, EAS activation can only be initiated by selected government agencies, such as NWS. This notification method requires that the public have access to broadcast devices and that these devices are turned on. This notification method is appropriate as part of the Middle Creek early warning system (EWS). To use this method successfully, the County must identify and work with the agencies who can initiate the system. We learned during interviews with County and response individuals that there have been some issues activating EAS in a timely fashion.

Personal contact by emergency officials	This method relies on emergency personnel to go door-to-door to deliver warnings. Or, emergency personnel can notify groups of residents by using bullhorns or loud speakers from patrol cars or other vehicles while driving through neighborhoods.	It is difficult to reach all individuals at risk in a timely manner. During interviews with emergency personnel, we learned that the fire departments estimate 8 minutes is required per household for door-to-door notification. This notification method is appropriate, but must be used in addition to other notification methods. It is useful particularly in areas where responders know residents will need assistance. Any information provided to the public can include a statement encouraging them to take responsibility for personal contact with neighbors who might not get the message otherwise.
Commercial broadcast radio	Warning information can be disseminated quickly to the public by commercial radio stations. In addition to serving as a broadcast method for EAS, commercial radio stations can broadcast information provided to them by local emergency management officials. This requires the cooperation of the radio station. The likeliness of this working successfully increases if the warning agency and radio station have an established relationship.	Commercial radio can quickly reach a large number of people. However, broadcasts will not reach people who do not have radios on. This method is less effective during sleeping hours. This notification method is appropriate, keeping in mind the limitations of use during sleeping hours.
Television	Warnings can be broadcast using over-the-air commercial television systems. This can be done by interrupting normal broadcasting or by displaying a scrolling message. In addition to EAS messages, television stations can broadcast information provided to them by local emergency management officials. Like broadcast radio, this will require cooperation with the television station and requires warning agencies, such as the County, to maintain a close working relationship with the stations.	A major advantage of television notification is the ability to display graphic information regarding evacuation routes, shelter locations and so on. While television is particularly good media during the evening, it is a poor choice during working or sleeping hours. This notification method will not reach people who do not have access to television or do not have their television on. We learned that most residents in the County use satellite broadcast television instead of cable television. Satellite television does not now have the capability of interrupting channels with a broadcast or displaying scrolling messages. Local broadcast stations, however, still can broadcast emergency information to satellite viewers, as long as viewers are watching their local channels.

		This dissemination method is appropriate for use as part of the Middle Creek EWS, keeping in mind the limitations of use described above.
Two-way radio	Two-way radios can be used for communicating information among emergency service personnel. Both police and fire bands are monitored by on-duty personnel and the use of scanners by the public increases the audience.	We learned during our interviews with responders and the public that approximately 30 individuals have hand-held 2-way radios (though not all of these individuals are located in the area at risk). Individuals interviewed value having the two-way radios. This notification method may not be appropriate for distribution to all of the public-at-risk in the Middle Creek inundation area.
Telephone, automated dialing system (commonly referred to as Reverse 911)	An automated dialing system provides the capability to communicate a message quickly without dispatchers having to make the calls. Such a system works as follows: 1. Emergency planners identify beforehand a group to whom emergency information should be communicated. This list includes the phone numbers of those in the group. 2. Emergency planners also prepare (and with some systems record) the message that is to be communicated to the group. 3. When a threat is identified, the automated dialing system is activated. The method of activation varies from one vendor to another but the result is the same with all: The system dials the list from Step 1 and communicates the message from Step 2.	The method is capable of reaching large groups of people quickly. We recognize the County is currently implementing an automated dialer system. The automated dialer system can provide different messages to different geographic regions. For example, a message to evacuate immediately can be sent to residents at the base of the canyon. A different message can be sent to residents of Bellgrade, who might be asked to shelter in place. This notification method will not reach individuals who do not have a telephone. Many people voiced concerns during our interviews about the large number of people in the area who do not have a land line telephone. The County system will not immediately be capability of calling cellular telephones. However, we understand that this feature might be implemented in the future. This notification method is appropriate, keeping in mind the limitation of reaching those who do not have landline telephones.
Telephone, dispatcher-dialed	Warning information can be communicated using common telephone equipment that is dialed by an operator or dispatcher.	This is best for notifying a limited number of individuals. The dispatcher can track who has received warnings and can deliver specific messages to individuals. Dispatcher dialing can be time consuming, with unpredictable numbers of individuals spending time inappropriately. This might be appropriate for calling a selected, few residents

		but not for contacting all residents in the inundation area – even those directly at the base of the canyon.
Citizen phone tree	A phone tree involves calls to several individuals, each of whom is responsible for calling others. This speeds dissemination of information. However, if an individual is unreachable, provisions must be made to ensure that those lower on the tree are contacted.	Based on interviews with the public, we learned that the residents of the Sourdough Fire Department have a phone tree in place. In this case, emergency personnel contact one individualn and that individual activates the phone tree (Neighborhood Network). According to residents interviewed, the Neighborhood Network worked successfully to notify residents of that community during a recent fire. However, there is general agreement that the phone tree is not quick enough, given the short flood travel times in the area. This notification method is appropriate here for disseminating information to a small community when time is available. However, it is not likely this would work as well for the populations further downstream as it does for the close-knit community at the base of the canyon. Also, it is not practical to rely on this method alone for notification of individuals who have less than 30 minutes to evacuate. There is not enough time for all calls to be disseminated and it is not certain that those responsible for making calls will be successful at doing so (the callers are among those who will need to evacuate immediately).
Sirens	Sirens can be used to alert residents of emergency conditions. Some siren systems can be programmed to broadcast messages along with a tone alert. Sirens can broadcast for a limited distance; this distance varies by siren type and by vendor. Thus multiple sirens are typically required for any large area. Siren contractors must determine how many sirens are required for the area that needs to be warned.	Siren systems are costly to implement and require ongoing maintenance and repair. Without adequate maintenance, sirens can fail to activate. Sirens can only broadcast a certain distance and are not designed to be heard indoors. This notification method is appropriate for reaching individuals outdoors. However, we learned during interviews with Forest Service personnel that there are environmental concerns for implementing sirens in the canyon. Also, Forest Service personnel expressed concern over the appropriateness of sirens to prompt the transient population within the canyon to take action, since visitors would not know what to do. Sirens may be appropriate for implementation at the base of the canyon but factors such as cost, maintenance concerns, reliability and broadcast range must be considered when

		making the decision on whether or not to implement this notification method.
Internet Web site	A Web site can be developed and used to disseminate information to the public.	The County Emergency Management Web site and others in the area can post information to keep the public informed before, during and after an emergency. For example, during interviews with emergency personnel and the public, we learned that the Rae-Sourdough Fire Department can add information to their Internet site from a mobile computer. This Web site was reportedly used widely by individuals in the Sourdough district during the last fire in the area. This notification method requires that individuals have computers, access to the Internet and are searching for information. This method is appropriate for providing information to residents who seek it but is not appropriate for providing quick emergency notification as part of the Middle Creek EWS.
E-mail	Warning messages can be sent via e-mail from emergency services personnel/dispatchers to individual e-mail accounts for the population-at-risk.	This requires citizens to have a computer, access to an e-mail account and be actively checking e-mail to receive the notification. Use of e-mail may be appropriate during working or waking hours but is a poor choice for sleeping hours. Although this notification method may be a good approach for sharing information with citizens who want information sent to their e-mail accounts, it is not an appropriate method for sending emergency notification as part of the Middle Creek EWS.
Paging	Pages can be initiated by dialing individual pager(s) manually or by automatically dialing groups of pagers using an automated dialer as described above.	The method has the capability for reaching large groups of people quickly if an automated dialing service is used and pager numbers are kept up to date. This notification method will not reach individuals who do not have a pager. This notification method is appropriate, keeping in mind the limitation of reaching those who do not have pagers.

Desktop data delivery	Specialized tools are available that allow pop-up messages to be sent to individuals who wish to be included via their online computers. Pop-up messages can provide basic information and links to additional information and can include images or sounds. For example, a tool such as the Digital Information Network runs in the background of a user's online computer and checks sources for notices to post, such as NWS-issued watches. If notices are found, they are shown with crawler messages and can include maps and siren sounds, as well. All features are customizable for client needs.	This requires citizens to have a computer and access to an e-mail account. Use of desktop data delivery may be appropriate during working or waking hours but is a poor choice for sleeping hours. This method is appropriate for providing notification as part of the Middle Creek early warning system if it is used in combination with other methods and keeping in mind the limitation of reaching those who do not have a computer or reaching individuals during sleeping hours.
Roadway warning	Motorists can be advised of a flooded (or potentially flooded) roadway with roadway signs. Variable message signs can operate at fixed locations or as mobile applications. Event-specific messages are manually programmed and displayed on approach to flooded or potentially flooded roadways. Automated signs are designed so that, once water on the roadway reaches a certain height, the signs are activated automatically. Static warning signs can be put in place in advance of a flooding situation to advise motorists that, when conditions warrant, specific actions should be taken, such as CLIMB TO SAFETY or DO NOT DRIVE THROUGH FLOODED ROADWAY. The signs do not change. Often times, static warning signs are used in conjunction with automated flashing lights. Roadway signs can be used in conjunction with portable AM radio highway advisory system. These systems can broadcast information to motorists with range of the units. Local emergency personnel can program information to be disseminated over the portable radio.	Variable message signs can be costly to implement and to maintain. Automated signs and flashing lights depend on sensors for activation; these sensors must be maintained. Signs and lights can be turned on/off from a central office or onsite. Variable message signs, automated signs or static signs used with a portable radio system are appropriate for implementation as part of the EWS, particularly for warning that major roadways are closed. We learned that Montana Department of Transportation has 2 variable message signs in place on major roadways. We learned the County has 3 Highway Advisory Radio Portables. These are trailer mounted AM radios that broadcast on either 1600 or 1700 kHz . These can be used to provide messages to motorists. Static message signs are a cost effective way of alerting motorists to areas that may be dangerous. However, since the sign does not change and lights do not flash, the motorist has to decide when conditions warrant caution. Static CLIMB TO SAFETY signs are not appropriate for implementation in the canyon, according to National Park Service personnel, due to high vandalism in the area.

Middle Creek Stakeholder Opinions and Desires for Public Notification

On November 6-7, 2007, we conducted interviews with representatives of DNRC, Gallatin County, City of Bozeman, Gallatin County staff, emergency responders from fire districts, Middle Creek Water Users Association, National Forest Service and approximately 20 public members. We include here key opinions and desires regarding public notification expressed during those meetings:

- Emergency responders suggest that notification should be sent to them or to dispatch first, not directly to the public.

- People residing at the base of the canyon want to be notified instantly if sensors detect a sudden failure of the dam. Individuals interviewed expressed strongly their need for automated notification. They are not comfortable relying solely on dispatch or their existing neighborhood network system.

- The public interviewed would like sirens installed in the neighborhoods at the base of the canyon. They suggest the sirens be triggered automatically.

- Anderson school has access to information distributed through the fire department two-way radio system as one of the school employees is a firefighter and carries the radio with her.

- The public suggest that two types of EWS (notification) systems might be needed, one for those who have little time to evacuate and a different one for those who have a longer period of time.

- Many individuals interviewed suggested that they are willing and capable of keeping a portable warning device (such as a pager or radio) operational in their homes.

- The interviewees generally agreed that most people downstream of the dam do not understand they are in an inundation zone, with the exception of those living closest to the dam. The County GIS department had developed an inundation map and is interested in sending this to residents in the inundation zone.

- Adding "climb to safety" signs not feasible in canyon due to high vandalism but interpretive panels at campsites might be feasible for educating recreationists.

- The public is very concerned that they do not know what actions to take once they receive notification. They are concerned that no dam failure response plans are in place specifically for evacuation for dam failure. They want plans developed in parallel with the instrumentation portion of the EWS. They suggest these plans are detailed enough to identify evacuation routes and shelters/safety zones. For example, the schools at the base of the canyon are developing and practicing their own response plans. One school reported it can load all students and staff on busses in under 12 minutes. But they do not know where to evacuate to; they strongly voiced the need to have this information soon.

Notification Methods used in Other Early Warning Systems

Best management practice for notification of the public is to use multiple forms of notification, coordinate with the media and document notification procedures. Results of a survey conducted of existing flood warning systems show that commonly selected methods include local radio, local television, Internet and automated dialer (reverse 911) telephone.

Examples of how other early warning systems notify the public are included below:

- City of Boulder, CO. The City of Boulder, CO, is located along Boulder Creek and is one of the most dangerous canyons for loss of life from flooding. The City has implemented multiple methods for notifying the public in the event of imminent flooding. These include messages disseminated by broadcast media, cable interrupt, automated calling system to residents, National Weather Radio (NWR) and sirens. All of these methods are activated by emergency managers or NWS.
- City of Fort Collins, CO. A flash flood in July 1997 resulted in 5 deaths and over 60 injuries that required hospitalization. Since then the City has implemented a system to monitor and warn of flash floods. The primary public notification component is coordination with broadcast media, the Reverse-911® autodialing system, which allows pre-recorded messages to be sent to approximately 200 residents per minute and NWR.
- Maricopa County, AZ, Skunk Creek. An updated hydrologic study found that 17 homes in Maricopa County were in the Skunk Creek floodway. Estimates showed that residents of these homes would have under 35 minutes to evacuate once flooding was detected by sensors upstream. Maricopa County Flood Control District assessed the situation and determined that due to the short time available, these residents must be notified directly by their system. Each adult in the identified households was provided with a pager that would sound an alert and provide a brief text message when a threat was detected. Residents were also provided with evacuation plans that instructed them on what routes to take and where to go during a flood. Providing warning to these residents was a temporary measure until the homes could be removed from the floodway through a voluntary buy-out program. When homes were removed from the floodway, residents returned their pagers. All homes in the floodway have now been removed.
- Casitas Dam, CA. U.S. Bureau of Reclamation's (BOR) Casitas Dam, located near Ventura, California, underwent a dam safety modification from June 1999 to November 2000. Responding to concerns of potential dam weakening during construction, expressed at pre-construction public meetings held in 1998, Reclamation funded the design and installation of an early warning system. The system consisted of 11 sirens with the ability to broadcast either a pre-recorded or a live announcement. A siren test in January 2000 malfunctioned and the system broadcast the message "This is an emergency. Find high ground now" for 15

minutes, leading many to attempt evacuation. Once the dam safety modification was completed, the siren system was turned over to Ventura County for operation.

- Turtle Creek Dam, KS. During a dam safety modification at Turtle Creek Dam, Kansas District Corps of Engineers implemented an early warning system. The system is designed to notify the public-at-risk by using 6 sirens located throughout the inundation area and in-door alarms installed in vulnerable facilities such as schools. Sirens installed have voice and tone alert. The early warning system is to be removed once modifications on the dam are complete.
- Hosler Dam, Oregon. Because of the close proximity of the Hosler Dam to the City of Ashland and the relatively short evacuation notice, the Federal Energy Regulatory Commission (FERC) required the City to install an audible emergency system. The system consists of 4 sirens with voice and tone capability distributed in the inundation area (City of Ashland 2004). Sirens are activated manually by city personnel. We learned from an interview with City of Ashland public works department that the purpose of the sirens is to expedite evacuation of an area that is a large greenbelt. The area is full of tourists in the summer. The City of Ashland has a long-term plan to implement an automated dialer system for notifying residents within the inundation area.
- National Monitoring Center (NMC). The U.S. Bureau of Indian Affairs (BIA) and the BOR provide flood threat detection and notification for all Native American Indian Reservations with BOR dams. The NMC provides a central location for these activities. Once a threat condition is recognized by sensors and a data management application, an automated message is sent to the NMC and local emergency officials. NMC then calls emergency officials downstream of the dam to ensure the message has been received. The local officials are responsible for notifying the public.
- City of Austin, TX. The City of Austin is subject to significant flash floods. The City has a sophisticated system for monitoring flood threats. Public notification is accomplished by an automated dialer system initiated by the City's emergency management team. The City also has a series of automated gates at dangerous low water crossings. When water reaches a pre-determined level at the crossing, engineering staff close the gates remotely. Gates have flashing lights and static warning signs. The City is acquiring and installing flashing lights and static signs at other hazardous water crossings.

Research in 2006-2007 in Austin was conducted to determine how the public prefers to be warned of flood events. The study found that the public prefers the broadcast media during non-sleeping hours, while sirens, phone calls and door-to-door notification are preferred during times when the public is typically asleep. These findings are similar to those from studies in Boulder, CO and Denver, CO.

Possible Implementation for Middle Creek Dam

During interviews we learned that the County and emergency responders want to select the best method for public notification. With that in mind, we offer below some simple measures that can be implemented quickly without great expense. These include:

1. Determine a solution for quick EAS activation. If this can be accomplished, the public can install devices in their homes, such as NOAA Weather Radios or the Informer, that sound an alarm when EAS is activated.
2. Continue with automated dialing system implementation and, if possible, add the capability for people to add their cell phone numbers into the system.
3. Maintain rapport with broadcast media. Provide broadcast media with information about the early warning system so that if emergency information on the dam must be disseminated by the media, all players are familiar with each other and know what actions to take.
4. Regardless of notification methods utilized, the County must document procedures in a notification plan.

Measures that will enhance public response to notification include:

1. Inform citizens of the real risk. We sensed a lot of confusion about the stability of the dam, its susceptibility to earthquake hazards and about who is in the inundation zone. We learned that a map has been developed and that County staff can send this map to all residents in the floodplain. This should be accompanied with relevant information so those receiving the map are not led to believe the risk is greater than it really is. However, it is important to recognize that even a small risk is important to these individuals and should not be taken lightly.
2. Identify and provide information to the public on evacuation routes and shelter locations/meeting points. One of the greatest concerns voiced by the public, the County Commissioner and others, is that the public does not have any information on what actions to take once the residents are alerted. Residents asked pointedly that these plans be developed now, not after the monitoring and notification components are put in place.

Recommendations for Response Planning

Implementation of either preliminary design option requires the development of response plans for citizen evacuation. It is understood that notification of citizens along Hyalite Creek is the responsibility of County and local response personnel.

In addition the Middle Creek Emergency Action Plan must be updated to incorporate aspects of the early warning system if one is installed.

Estimate of Probable Cost

An engineering estimate of probable cost to implement the preliminary design (both options 1 and 2) is provided (Table 14). The total cost is broken into three areas which include final design and construction planning, capital costs, and construction.

Final Design and Construction Planning

The implementation of either preliminary design option will require the development of a final design including a set of construction plans before the early warning system can be built. The final design for Option 2 should include a physical radio path study (to confirm the theoretical results presented in the feasibility report), equipment specification, determination of final sensor configuration (sensor type and location), details for equipment integration, interface planning (radio to microwave interface at County radio tower, CAD interface at dispatch center) and development of installation plans. The product from this work phase will be a complete set of construction plans that can be used to solicit bids for the construction of the system. Estimated costs to complete the engineering design and to develop the constructions plans are shown (Table 14).

Table 14. Final Design and Construction Planning Cost Estimate

Work Task	Option 1 – OneRain StormLink	Option 2 – VHF Radio
Radio telemetry planning/physical testing	$0	$5,200
Radio frequency licensing	$0	$2,000
Sensor specification (type and location)	$4,000	$4,000
Equipment integration planning (includes development of decision logic to identify dam failure condition that would reside on local data logger)	$4,000	$14,000
Software integration planning	$0	$6,000
Installation/construction planning	$4,200	$4,200
Preparation of construction plans/specs	$5,600	$8,600
Final Design Sub-Total	**$17,800**	**$44,000**
Contingency 20%	**$3,560**	**$8,800**
Final Design Total	**$21,360**	**$52,800**

Capital Expenditures and Initial One-Time Fees

The capital costs and one-time set-up fees associated with both design options are estimated (Table 15).

Table 15. Capital Expenditures and Initial Fees

Description	Option 1 – OneRain	Option 2 – VHF Radio
Middle Creek Dam Station		
Electronics enclosure	$824	$824
30 foot Rohn tower	$950	$950
Float switch (4 @ $603)	$2,508	$2,508
Data logger	$1,700	$1,700
StormLink telemetry system	$2,541	$0
StormLink communications engine	$2,508	$0
VHF ALERT radio	$0	$800
VHF radio antenna/cables	$0	$100
Intrusion sensor (door switch)	$139	$139
Solar panel (20 watt)	$732	$732
Grounding kit	$20	$20
Misc. hardware (conduit, connectors, etc.)	$500	$500
Middle Creek Dam Station Sub-Total	**$12,422**	**$8,273**
Hyalite Creek Stream Gage		
Electronics enclosure	$824	$824
30 foot Rohn tower	$950	$950
Float switch (3 @ $603)	$1,809	$1,809
Continuous water level sensor	$2,105	$2,105
Data logger	$1,700	$1,700
StormLink telemetry system	$2,541	$0
StormLink communications engine	$2,508	$0
VHF ALERT radio	$0	$800
VHF radio antenna/cables	$0	$100
Intrusion sensor (door switch)	$139	$139
Solar panel (20 watt)	$732	$732
Grounding kit	$20	$20
Misc. hardware (conduit, connectors, etc.)	$500	$500
Hyalite Creek Stream Gage Sub-Total	**$13,828**	**$9,679**
High Flat Receiver/Radio Repeater		
Electronics enclosure	$0	$824
VHF ALERT transceiver	$0	$800
Data logger/repeater	$0	$7,500
VHF radio antenna/cables	$0	$1,500
Solar panel	$0	$732
Grounding kit	$0	$20
Integration components to County equipment	$0	$5,500
High Flat Receiver/Radio Repeater Sub-Total		**$16,876**
County EOC Receiver		
Electronics enclosure	$0	$824
VHF ALERT receiver	$0	$800
ALERT decoder (audio/digital modem)	$0	$2,500
VHF radio antenna/cables	$0	$500
Grounding kit	$0	$20
Integration components to County equipment	$0	$5,500
County EOC Receiver Sub-Total		**$10,144**
StormLink one-time setup	$1,020	$0
Terminal interface at EOC	$0	$5,500
High Flat, interface to County communications	$0	$10,000
Base station software/CAD interface**	$0	$20,000
Software training	$2,500	$2,500
Capital Costs Sub-Total	**$29,770**	**$82,972**
Contingency 20%	**$5,954**	**$16,594**
Capital Costs and Initial Fees Total	**$35,724**	**$99,566**

** - Note that the software/CAD interface is nebulous at this point and must be clarified during the final design. The cost to implement the software/CAD interface may exceed $20,000.

Construction

Construction, configuration and testing costs are estimated. These costs include installation of the monitoring network, installation of the telemetry system, installation and configuration of the software at the County Dispatch Center, integration of new software with County CAD system, and end-to-end testing (Table 16).

Table 16. Construction Costs

Description	Option 1 – OneRain StormLink	Option 2 – VHF Radio
Sensor/monitoring network	$25,000	$25,000
Satellite telemetry network	$0	$0
Radio telemetry network/tower interface/repeater	$0	$15,000
Base station software/CAD interface	$0	$23,200
System configuration and testing	$10,000	$20,000
Construction Sub-Total	**$35,000**	**$83,200**
Contingency 20%	**$7,000**	**$16,640**
Construction Total	**$42,000**	**$99,840**

Annual Operation and Maintenance

Costs are estimated for annually recurrent aspects of the system for both design options. These costs include service fees for telemetry, fees for OneRain services, and costs associated with equipment replacement and system maintenance (Table 17).

Table 17. Annual Operation and Maintenance Costs

Description	Option 1 – OneRain StormLink	Option 2 – VHF Radio
OneRain StormLink satellite fees	$1,080	$0
OneRain Alarm/Notification Service	$2,400	$0
OneRain Web data delivery (Contrail)	$25,344	$0
Maintenance/calibration/testing	$10,500	$10,500
Spare equipment	$3,500	$5,500
Management and administration	$2,500	$2,500
Annual O&M Sub-Total	**$45,324**	**$18,500**
Contingency 20%	**$9,065**	**$3,700**
Annual O&M Total	**$54,389**	**$22,200**

Required Maintenance

Maintenance is an aspect of the system that is frequently overlooked in the initial planning phases but is critical if the early warning system is to operate as designed over the long term. The system will fail if dedicated personnel, money and spare equipment are not available to maintain the system into the future. DNRC is committed to maintaining the dam instrumentation system. The maintenance responsibilities for the early warning system are to be determined.

Equipment and sensors should be inspected and tested once per month during the high risk period of May through September. All sensors should be calibrated once per year. Sensors may have to be winterized to minimize damage in freezing conditions. This is especially true if pressure transducers are to be used.

Spare Equipment

It is recommended that between 15% and 20% of the installed equipment be kept on hand as spare equipment to conduct emergency repairs during the year.

Development of Response Plans

It is recommended that specific response plans be developed to coordinate the logistics of public evacuation along Hyalite Creek. The citizens must know where to go and how to get there once an alarm is activated.

Update of Middle Creek Emergency Action Plan

The existing EAP must be updated to incorporate aspects of the early warning system.

Estimate of Total Probable Cost for Life of Project

For the purpose of estimating total probable cost, the life of the early warning system is estimated to be 10 years. The estimate of total probable cost is determined as the sum of engineering, capital, and installation costs which are considered one-time costs. Additionally the annually recurrent costs are added for the life of the project. The total cost is summarized for both preliminary design options (Table 18).

Table 18. Estimate of Total Probable Cost

Description	Option 1 – OneRain StormLink	Option 2 – ALERT Radio
Final design	$21,360	$52,800
Capital costs and initial one-time fees	$35,724	$99,566
Construction	$42,000	$99,840
Development of response plans	$15,000	$15,000
Update of Middle Creek EAP	$5,000	$5,000
Sum of One-Time Costs	**$119,084**	**$272,206**
Annually Recurrent Costs	**$54,389**	**$22,200**
Annually Recurrent Costs (for 10 years)	**$543,890**	**$222,000**
Estimate of Total Cost	**$662,974**	**$494,206**

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Appendix A – Theoretical Radio Path Analysis

The radio links from Middle Creek Dam and the stream gage in Hyalite Canyon below the dam are modeled using a point-to-point VHF radio link modeling application called MicroPath. The software estimates the relative strength of a radio signal between two locations. Losses due to diffraction, dispersion, and absorption are modeled using USGS 1-second digital elevation terrain data. The reliability of the radio link is evaluated for an operational radio frequency of **171.100 MHz**. This frequency is in the radio band of frequencies set aside by the FCC for communication of hydrometeorological data for public safety.

Radio links are evaluated from Middle Creek Dam and the Hyalite Creek stream gage to the following locations which are also shown on a map (Figure 4):

- Bridger Ridge – County radio tower
- High Flat – County radio tower
- Nixon Ridge – County radio tower
- Timberline – County radio tower
- EOC (Gallatin County Emergency Operations Center)
- Kenyon Water Tower
- Old Dispatch (Gallatin County Law and Justice Center)
- New Dispatch Center
- Cottonwood Fire Station

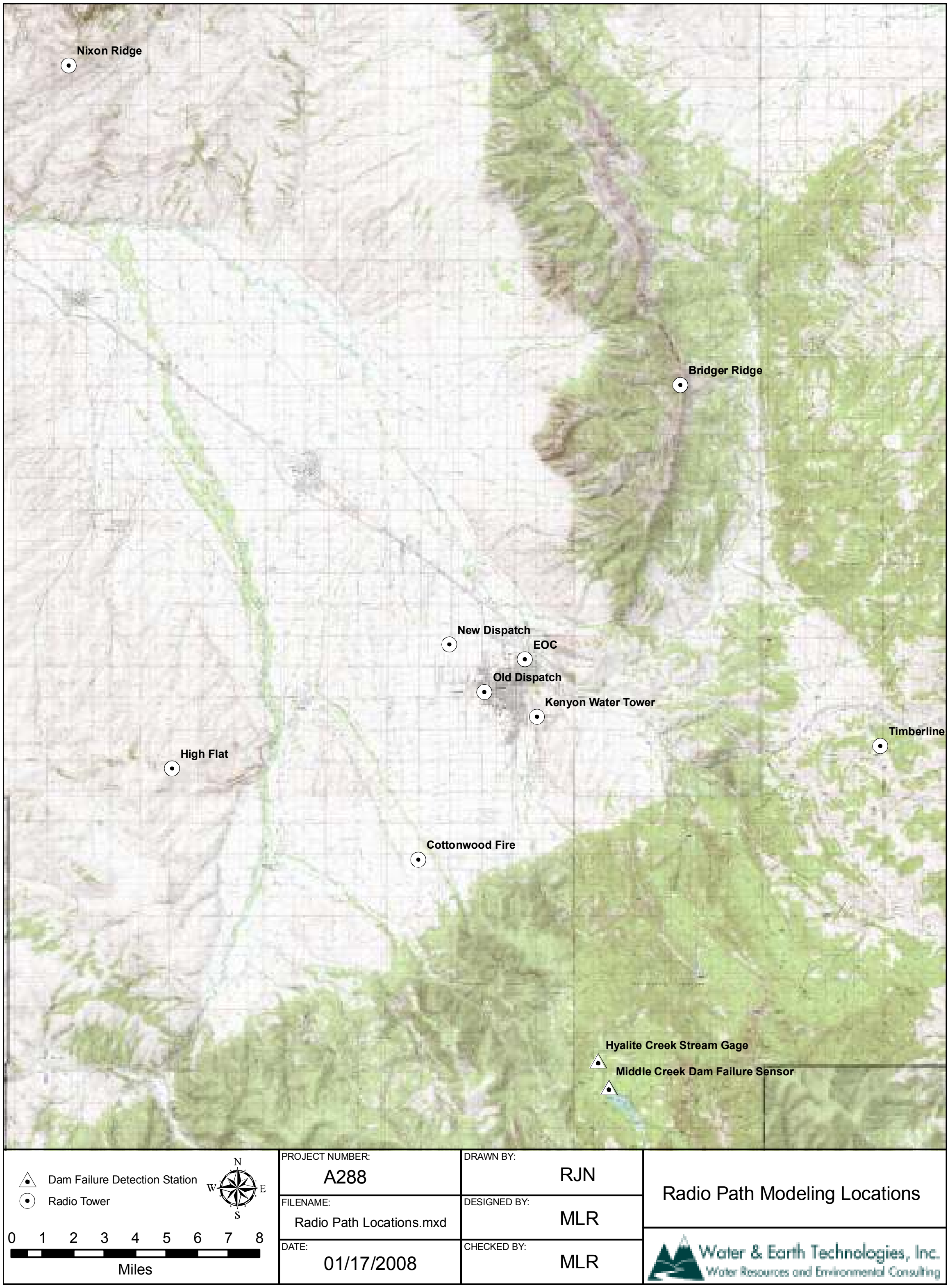


Figure 4. Radio Path Modeling Locations

The radio path modeling study makes several assumptions in terms of radio power and antenna characteristics. The assumptions used in the study are typical for radio and antenna systems employed with the ALERT radio protocol.

The radio emission and reception characteristics used in the modeling study are those for an industry standard radio transceiver (Table 19).

Table 19. Modeled Transceiver Characteristics

Attribute	Commercial Specification
Band (VHF)	146 – 174 MHz
Modeled Frequency	171.100 MHz
Antenna Impedance	50 Ohm
RF Output Power	5 Watt
Published Receiver Sensitivity	0.28dB µV (-118 dBm)
Modeled Receiver Sensitivity	-106 dBm

The published receiver sensitivity was decreased by 12 dBm to account for the noise floor inherent in any radio system and in particular, at a central radio tower.

The antenna characteristics used in the modeling study are as follows (Table 20).

Table 20. Modeled Antenna Characteristics

Description	County Towers	Base Locations	Middle Creek Dam	Stream Gage
Antenna Model	DB224 (VHF)	DB224 (VHF)	DB224 (VHF)	DB224 (VHF)
Band (VHF)	150-174 MHz	150-174 MHz	150-174 MHz	150-174 MHz
Radiation Pattern	Omni (360 deg)	Omni (360 deg)	Omni (360 deg)	Omni (360 deg)
Gain	6 dBd	6 dBd	6 dBd	6 dBd
Impedance	50 Ohms	50 Ohms	50 Ohms	50 Ohms
Antenna Height (AGL)	75 feet	50 feet	30 feet	30 feet
Line/Connector Loss	1 dB	1 dB	1 dB	1 dB

The effective radiated energy from each station is computed along with the losses and gains associated with the propagation of the radio transmission to each receiving location. A radio signal is degraded as it travels through the antenna cable, the air, through vegetation and over the local terrain. When the radio signal finally makes it to the receiver, its signal strength is reduced from what was transmitted. The receiver can only make sense of those signals that are above some minimum receiver sensitivity level.

The degradation of the radio signal due to the intervening terrain was modeled using both a Lee-Pequenard (multiple knife-edge) and Longley-Rice diffraction model. An additional 5.0 dB loss was assumed for signal attenuation due to foliage.

The quality and reliability of a radio path is measured in decibels (dB) and is described as "fade margin". Fade margin is computed as the received signal strength minus the receiver sensitivity. The fade margin is a parameter describing the amount by which the received signal level may still be reduced without causing the signal level to fall below the receiver's ability to produce an acceptable output signal.

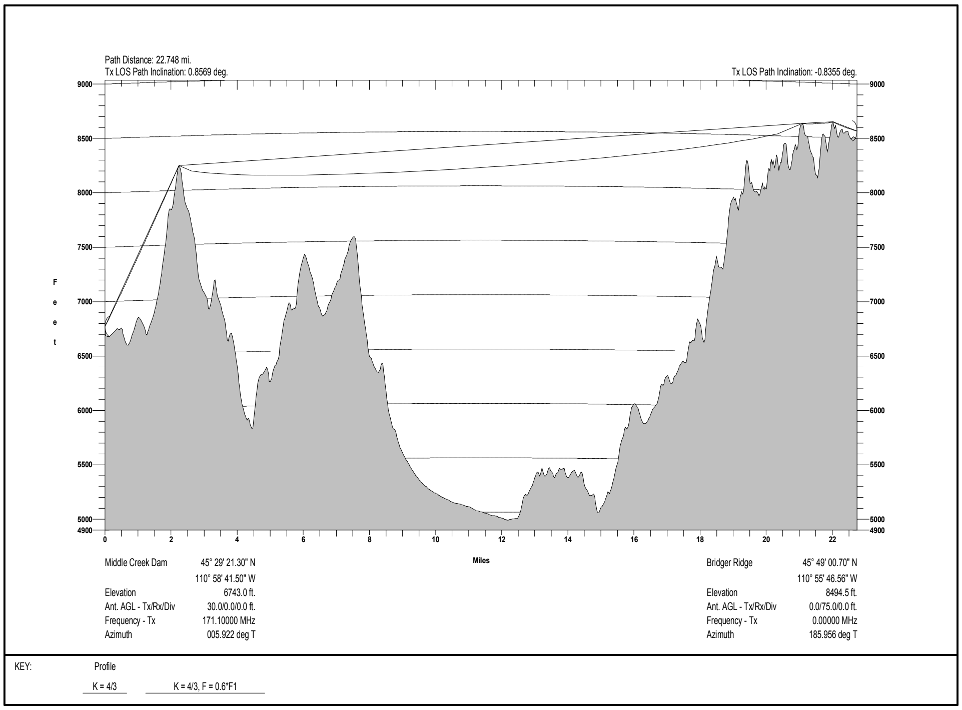
The radio path modeling results are shown (Table 21). Modeled fade margins greater than 20 dB are shaded in green and are considered to be "good" and should provide a reliable path for radio communications. Fade margins between 5 and 20 dB are shaded in yellow and are considered “marginal”. Fade margins less than 5 dB are shaded in red and are considered “poor”.

Table 21. Radio Path Modeling Results

Transmitting Location	Receiving Location	Distance between Sites (miles)	Fade Margin (dB)	Link Quality
Middle Creek Dam	Bridger Ridge	22.75	-4.34	poor
	High Flat	17.39	7.04	marginal
	Nixon Ridge	37.22	11.58	marginal
	Timberline	14.07	0.01	poor
	Eagle Head	19.63	8.17	marginal
	EOC	14.05	21.44	good
	Kenyon Water Tower	12.15	12.24	marginal
	Law and Justice	13.35	20.72	good
	Cottonwood Fire	9.55	2.5	poor
Hyalite Stream Gage	Bridger Ridge	21.94	-11.49	poor
	High Flat	16.63	23.32	good
	Nixon Ridge	36.31	-3.57	poor
	Timberline	13.64	-11.44	poor
	Eagle Head	20.31	-26.63	poor
	EOC	13.15	6.68	marginal
	Kenyon Water Tower	11.26	4.83	poor
	Law and Justice	12.44	6.33	marginal
	Cottonwood Fire	8.68	-0.79	poor

Plots showing the intervening terrain are provided for each path.

Terrain Plots



Path Distance: 22.748 mi.
Tx LOS Path Inclination: 0.8569 deg.
Tx LOS Path Inclination: -0.8355 deg.
Feet
Miles
Middle Creek Dam 45° 29' 21.30" N
110° 58' 41.50" W
Elevation 6743.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 005.922 deg T
Bridger Ridge 45° 49' 00.70" N
110° 55' 46.56" W
Elevation 8494.5 ft.
Ant. AGL - Tx/Rx/Div 0.0/75.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 185.956 deg T
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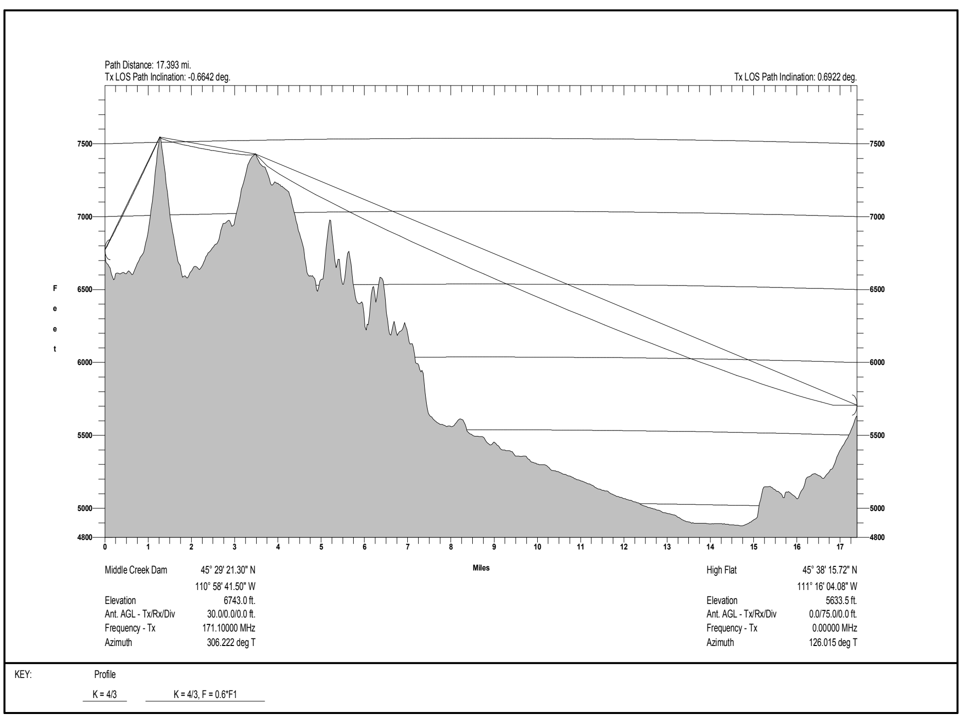
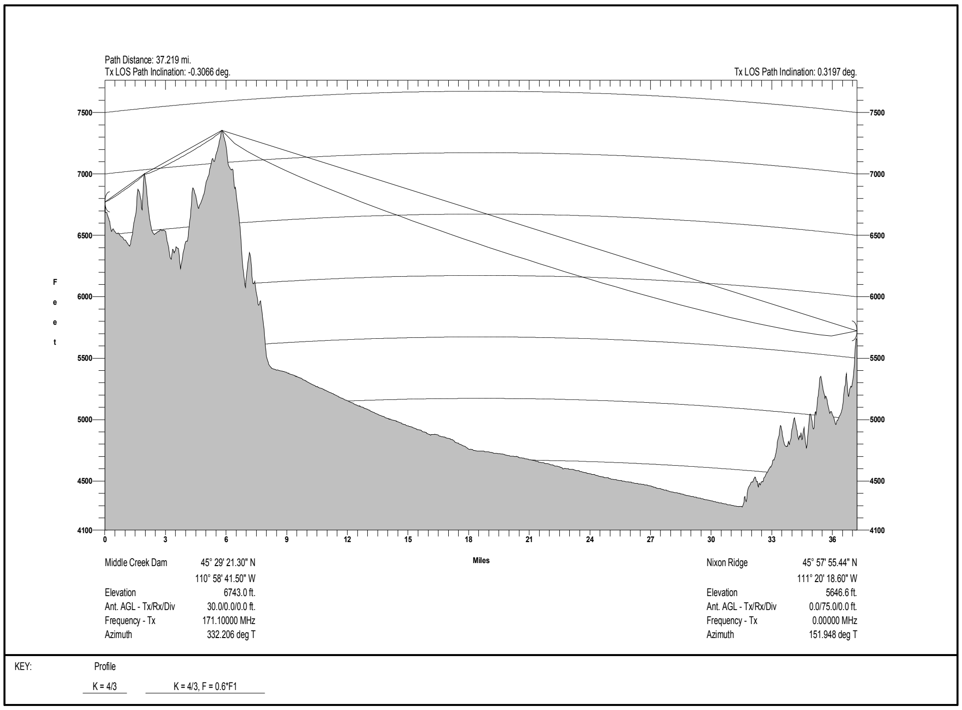
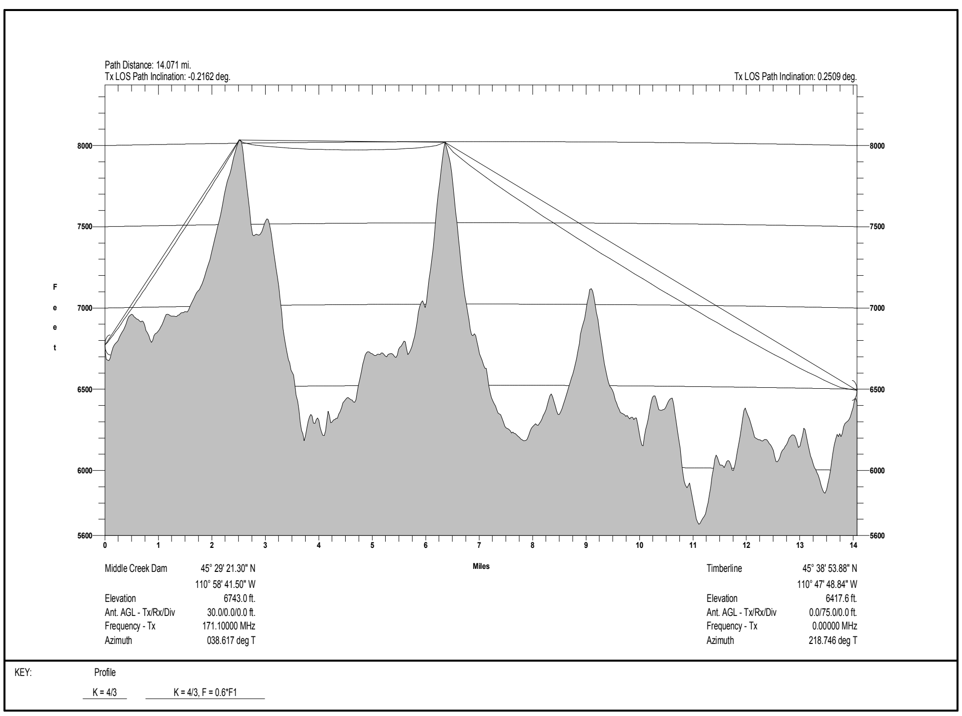
K = 4/3
K = 4/3, F = 0.6*F1



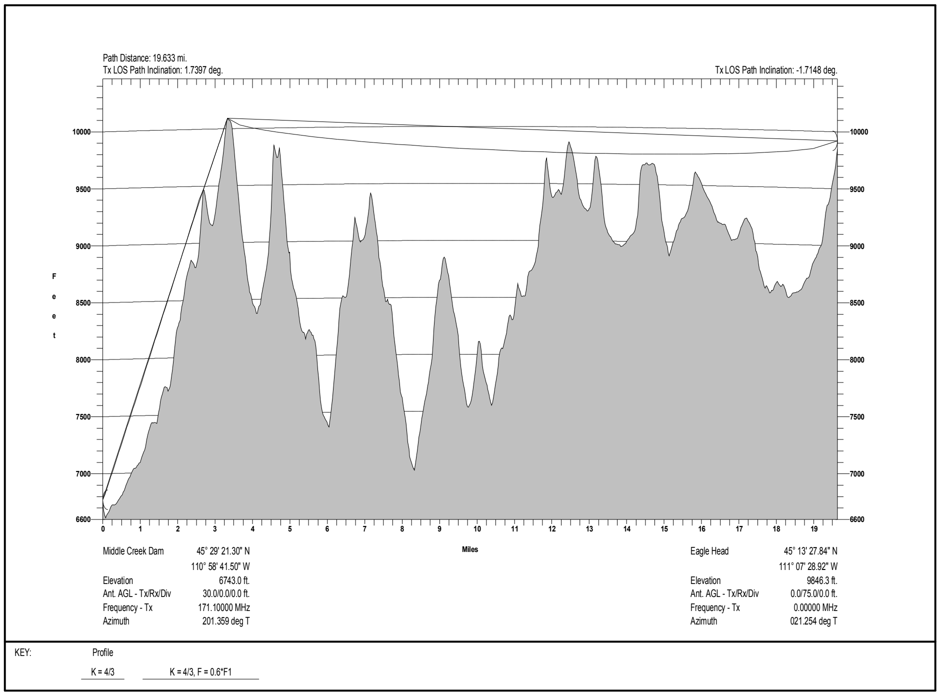
Path Distance: 17.393 mi.
Tx LOS Path Inclination: -0.6642 deg.
Tx LOS Path Inclination: 0.6922 deg.
Feet
Miles
Middle Creek Dam 45° 29' 21.30" N
110° 58' 41.50" W
Elevation 6743.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 306.222 deg T
High Flat 45° 38' 15.72" N
111° 16' 04.08" W
Elevation 5633.5 ft.
Ant. AGL - Tx/Rx/Div 0.0/75.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 126.015 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1

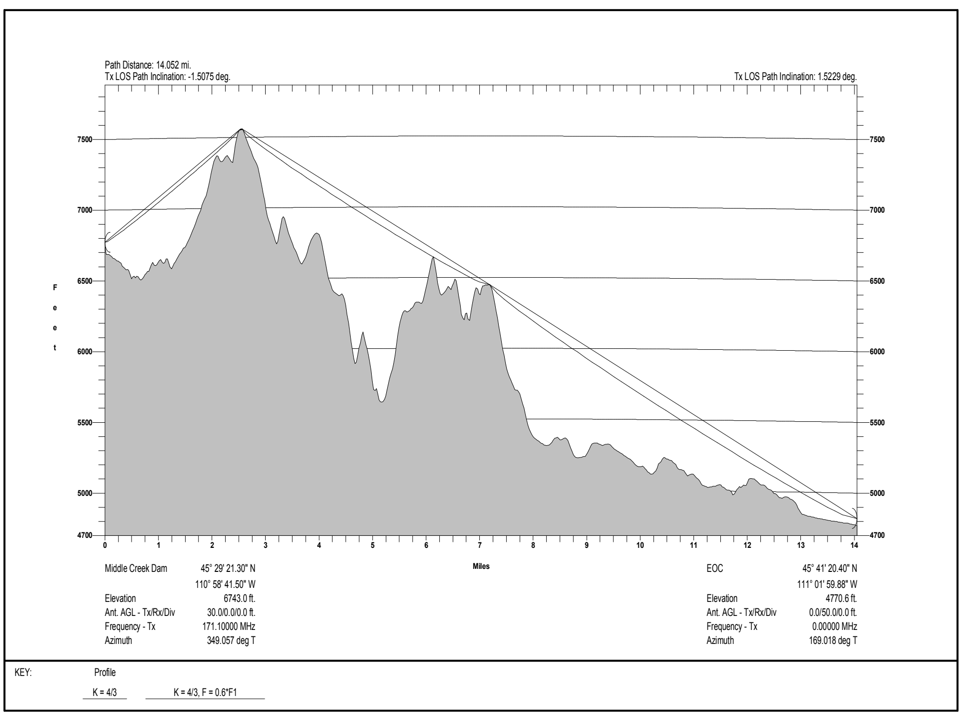


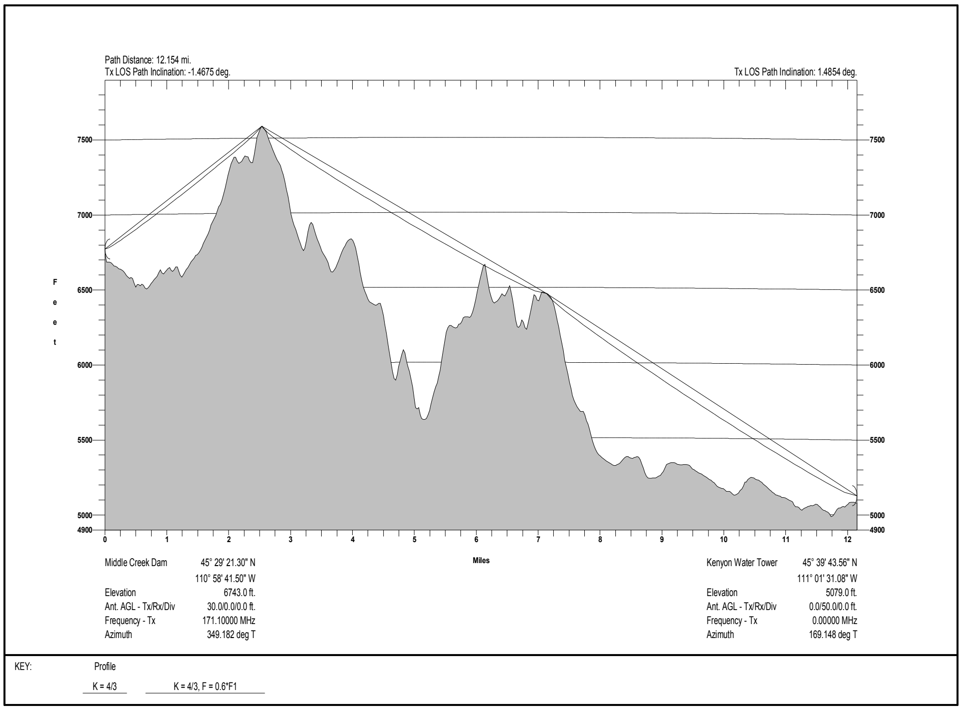
Path Distance: 37.219 mi.
Tx LOS Path Inclination: -0.3066 deg.
Tx LOS Path Inclination: 0.3197 deg.
Feet
7500
7000
6500
6000
5500
5000
4500
4100
0 3 6 9 12 15 18 21 24 27 30 33 36
Miles
Middle Creek Dam 45° 29' 21.30" N
110° 58' 41.50" W
Elevation 6743.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 332.206 deg T
Nixon Ridge 45° 57' 55.44" N
111° 20' 18.60" W
Elevation 5646.6 ft.
Ant. AGL - Tx/Rx/Div 0.0/75.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 151.948 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1

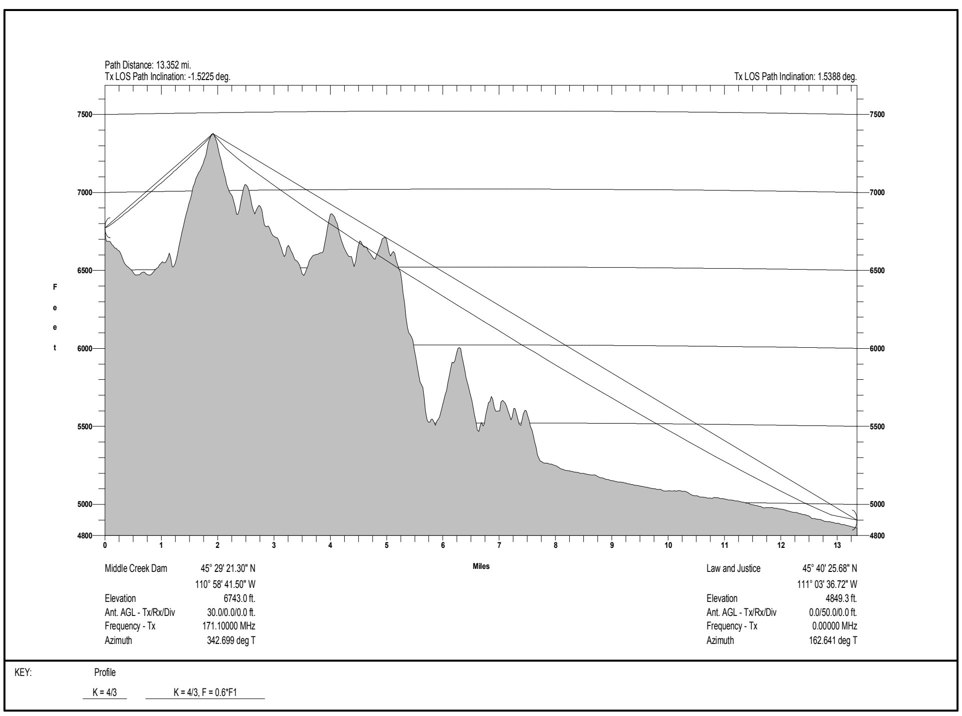


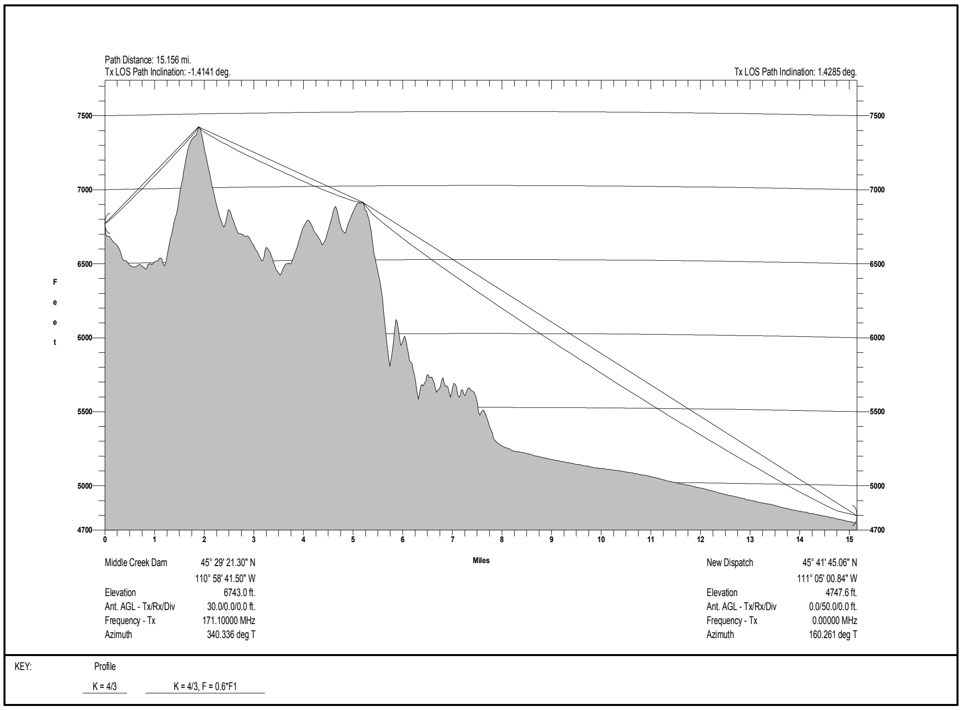
Path Distance: 14.071 mi.
Tx LOS Path Inclination: -0.2162 deg.
Tx LOS Path Inclination: 0.2509 deg.
Feet
8000
7500
7000
6500
6000
5600
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Miles
Middle Creek Dam 45° 29' 21.30" N
110° 58' 41.50" W
Elevation 6743.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 038.617 deg T
Timberline 45° 38' 53.88" N
110° 47' 48.84" W
Elevation 6417.6 ft.
Ant. AGL - Tx/Rx/Div 0.0/75.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 218.746 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1

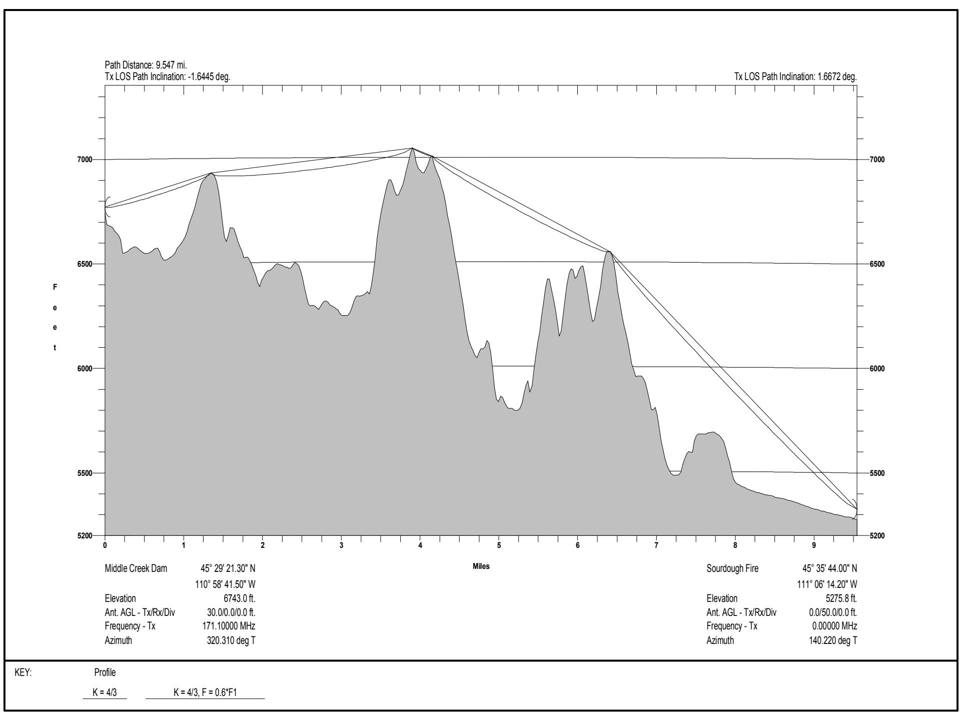

Path Distance: 19.633 mi.
Tx LOS Path Inclination: 1.7397 deg.
Tx LOS Path Inclination: -1.7148 deg.
Feet
Miles
Middle Creek Dam 45° 29' 21.30" N
110° 58' 41.50" W
Elevation 6743.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 201.359 deg T
Eagle Head 45° 13' 27.84" N
111° 07' 28.92" W
Elevation 9846.3 ft.
Ant. AGL - Tx/Rx/Div 0.0/75.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 021.254 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1

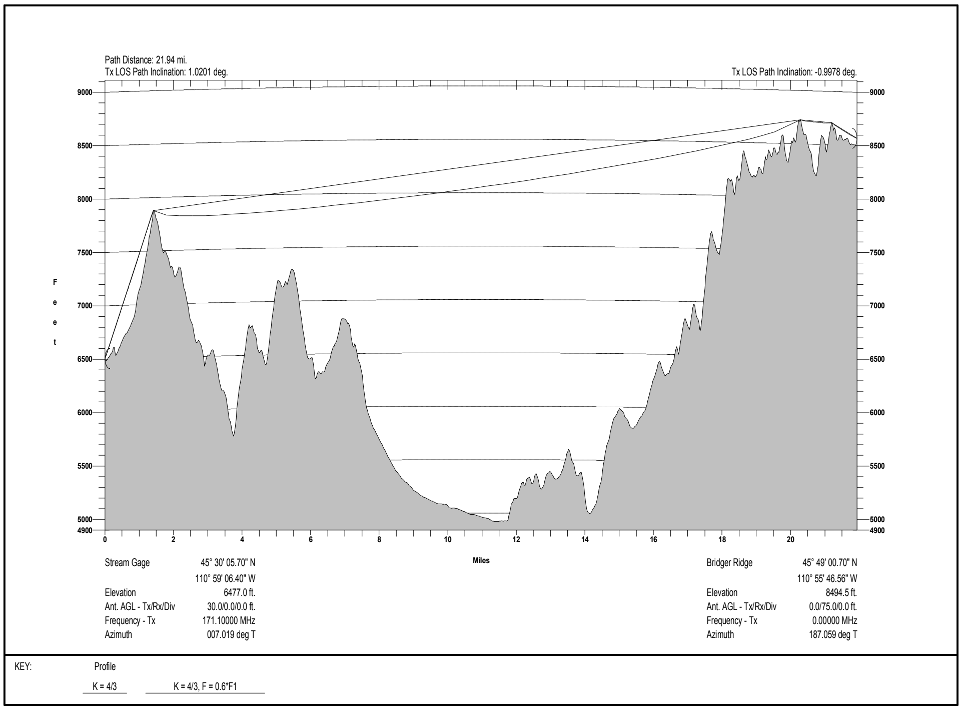

Path Distance: 14.052 mi.
Tx LOS Path Inclination: -1.5075 deg.
Tx LOS Path Inclination: 1.5229 deg.
Feet
Miles
Middle Creek Dam 45° 29' 21.30" N
110° 58' 41.50" W
Elevation 6743.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 349.057 deg T
EOC 45° 41' 20.40" N
111° 01' 59.88" W
Elevation 4770.6 ft.
Ant. AGL - Tx/Rx/Div 0.0/50.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 169.018 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1

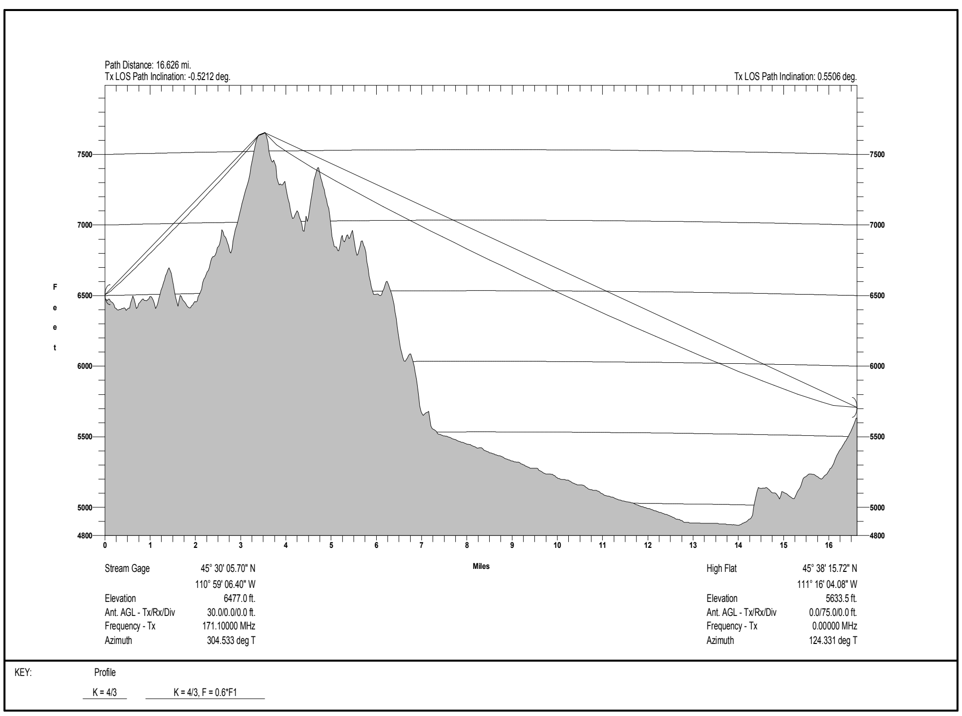

Path Distance: 12.154 mi.
Tx LOS Path Inclination: -1.4675 deg.
Tx LOS Path Inclination: 1.4854 deg.
Feet
Miles
Middle Creek Dam 45° 29' 21.30" N
110° 58' 41.50" W
Elevation 6743.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 349.182 deg T
Kenyon Water Tower 45° 39' 43.56" N
111° 01' 31.08" W
Elevation 5079.0 ft.
Ant. AGL - Tx/Rx/Div 0.0/50.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 169.148 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1

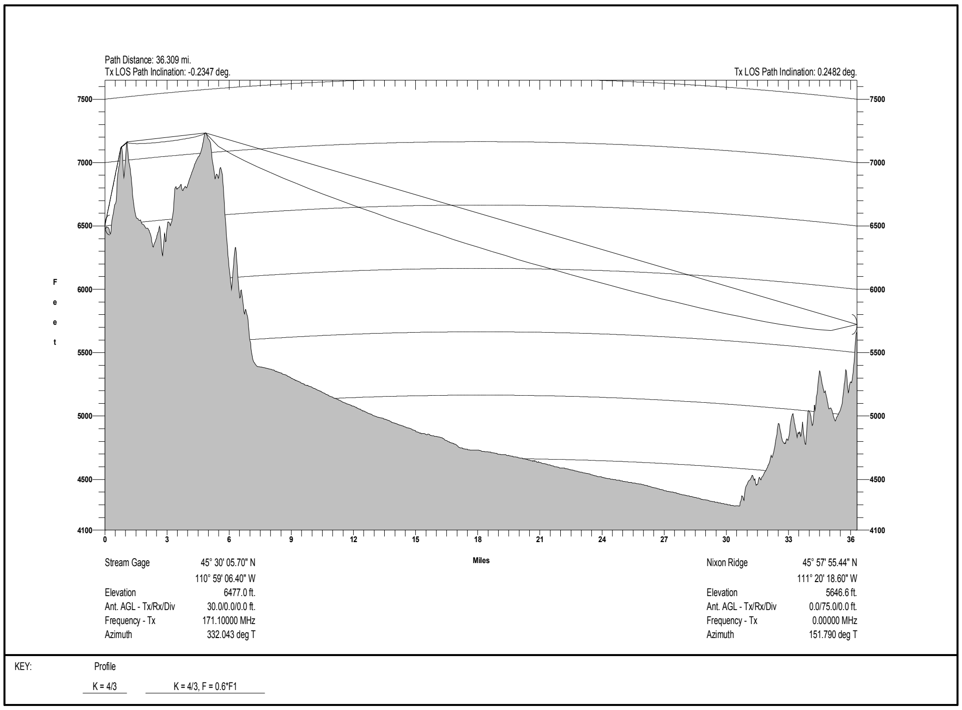

Path Distance: 13.352 mi.
Tx LOS Path Inclination: -1.5225 deg.
Tx LOS Path Inclination: 1.5388 deg.
Feet
Miles
Middle Creek Dam 45° 29' 21.30" N
110° 58' 41.50" W
Elevation 6743.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 342.699 deg T
Law and Justice 45° 40' 25.68" N
111° 03' 36.72" W
Elevation 4849.3 ft.
Ant. AGL - Tx/Rx/Div 0.0/50.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 162.641 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1


Path Distance: 15.156 mi.
Tx LOS Path Inclination: -1.4141 deg.
Tx LOS Path Inclination: 1.4285 deg.
Feet
Miles
Middle Creek Dam 45° 29' 21.30" N
110° 58' 41.50" W
Elevation 6743.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 340.336 deg T
New Dispatch 45° 41' 45.06" N
111° 05' 00.84" W
Elevation 4747.6 ft.
Ant. AGL - Tx/Rx/Div 0.0/50.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 160.261 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1

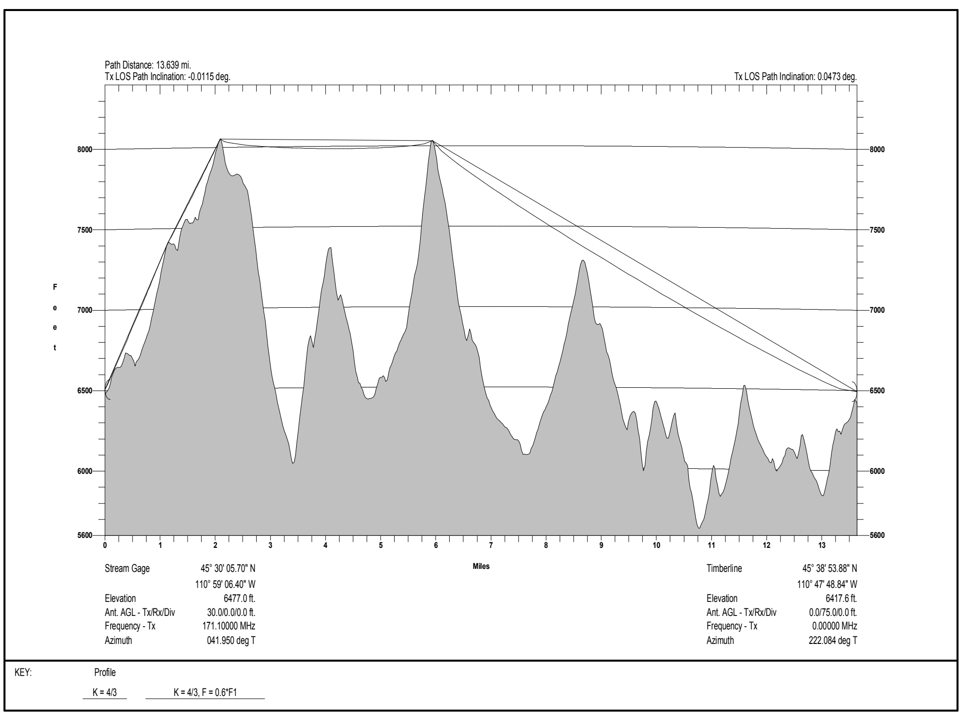

Path Distance: 9.547 mi.
Tx LOS Path Inclination: -1.6445 deg.
Tx LOS Path Inclination: 1.6672 deg.
Feet
Miles
Middle Creek Dam 45° 29' 21.30" N
110° 58' 41.50" W
Elevation 6743.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 320.310 deg T
Sourdough Fire 45° 35' 44.00" N
111° 06' 14.20" W
Elevation 5275.8 ft.
Ant. AGL - Tx/Rx/Div 0.0/50.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 140.220 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1


Path Distance: 21.94 mi.
Tx LOS Path Inclination: 1.0201 deg.
Tx LOS Path Inclination: -0.9978 deg.
Feet
Miles
Stream Gage
45° 30' 05.70" N
110° 59' 06.40" W
Elevation 6477.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 007.019 deg T
Bridger Ridge
45° 49' 00.70" N
110° 55' 46.56" W
Elevation 8494.5 ft.
Ant. AGL - Tx/Rx/Div 0.0/75.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 187.059 deg T
KEY:
Profile
K = 4/3
K = 4/3, F = 0.6*F1

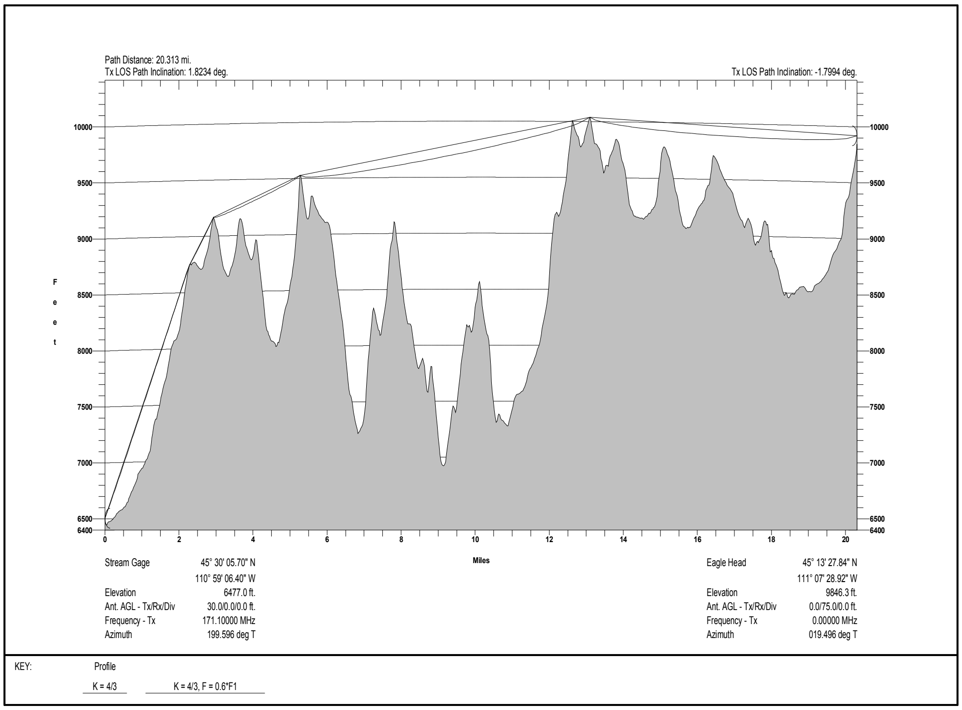

Path Distance: 16.626 mi.
Tx LOS Path Inclination: -0.5212 deg.
Tx LOS Path Inclination: 0.5506 deg.
Feet
Miles
Stream Gage
45° 30' 05.70" N
110° 59' 06.40" W
Elevation 6477.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 304.533 deg T
High Flat
45° 38' 15.72" N
111° 16' 04.08" W
Elevation 5633.5 ft.
Ant. AGL - Tx/Rx/Div 0.0/75.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 124.331 deg T
KEY:
Profile
K = 4/3
K = 4/3, F = 0.6*F1

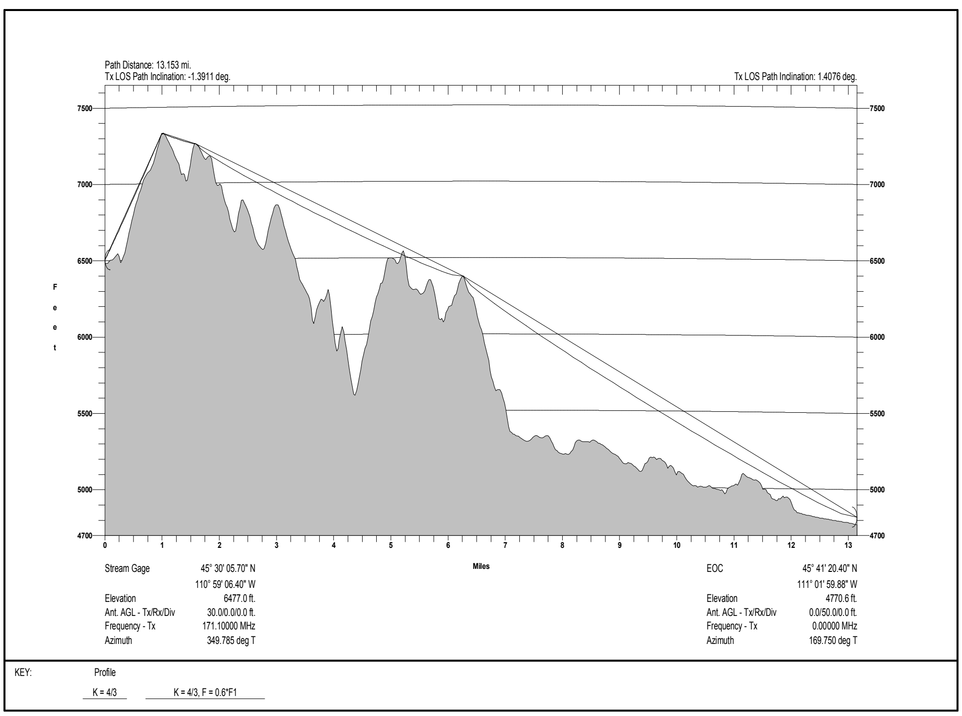


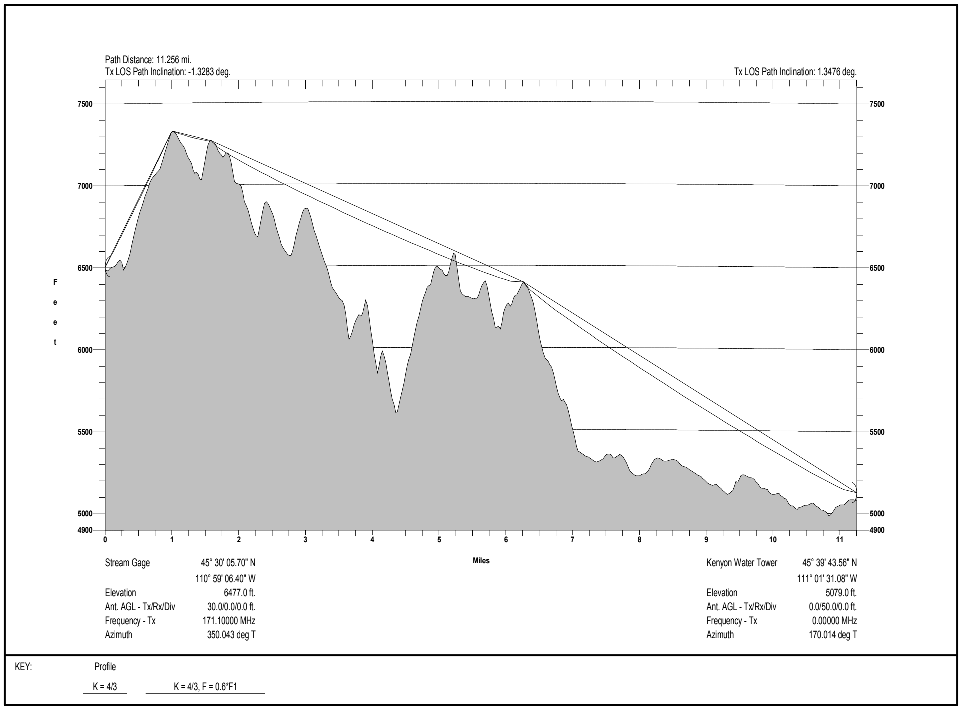
Path Distance: 36.309 mi.
Tx LOS Path Inclination: -0.2347 deg.
Tx LOS Path Inclination: 0.2482 deg.
Feet
Miles
Stream Gage
45° 30' 05.70" N
110° 59' 06.40" W
Elevation 6477.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 332.043 deg T
Nixon Ridge
45° 57' 55.44" N
111° 20' 18.60" W
Elevation 5646.6 ft.
Ant. AGL - Tx/Rx/Div 0.0/75.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 151.790 deg T
KEY:
Profile
K = 4/3
K = 4/3, F = 0.6*F1

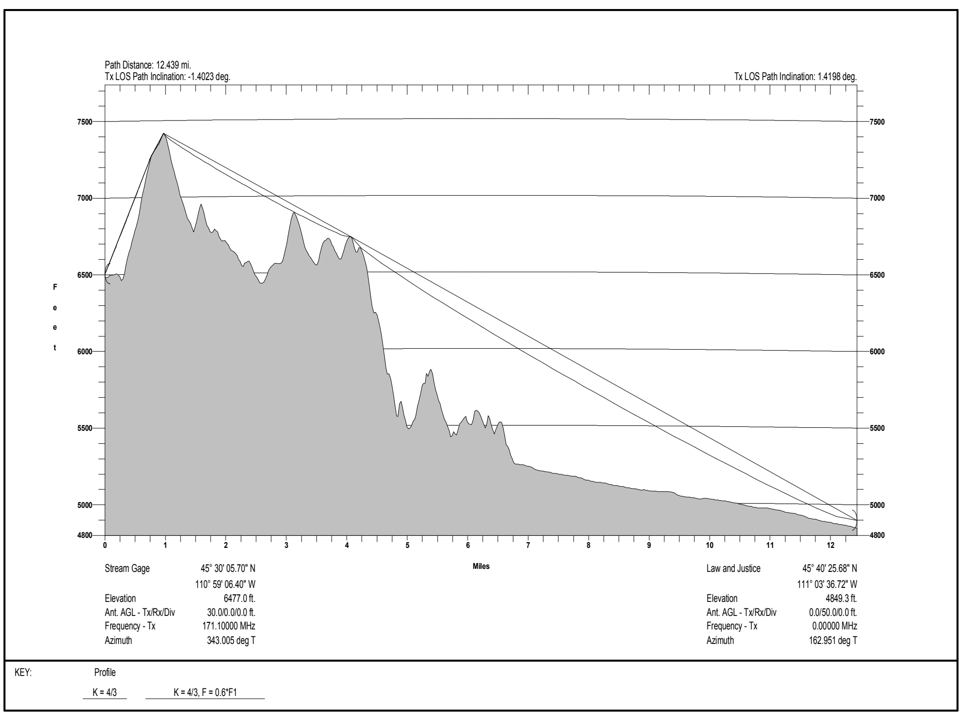


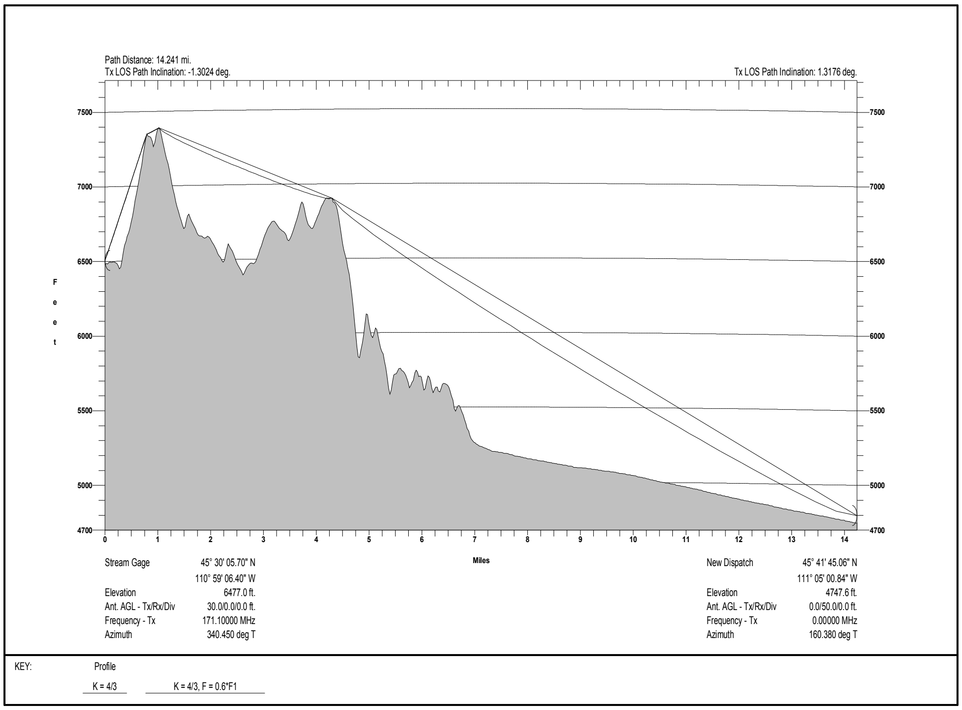
Path Distance: 13.639 mi.
Tx LOS Path Inclination: -0.0115 deg.
Tx LOS Path Inclination: 0.0473 deg.
Feet
Miles
Stream Gage
45° 30' 05.70" N
110° 59' 06.40" W
Elevation 6477.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 041.950 deg T
Timberline
45° 38' 53.88" N
110° 47' 48.84" W
Elevation 6417.6 ft.
Ant. AGL - Tx/Rx/Div 0.0/75.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 222.084 deg T
KEY:
Profile
K = 4/3
K = 4/3, F = 0.6*F1

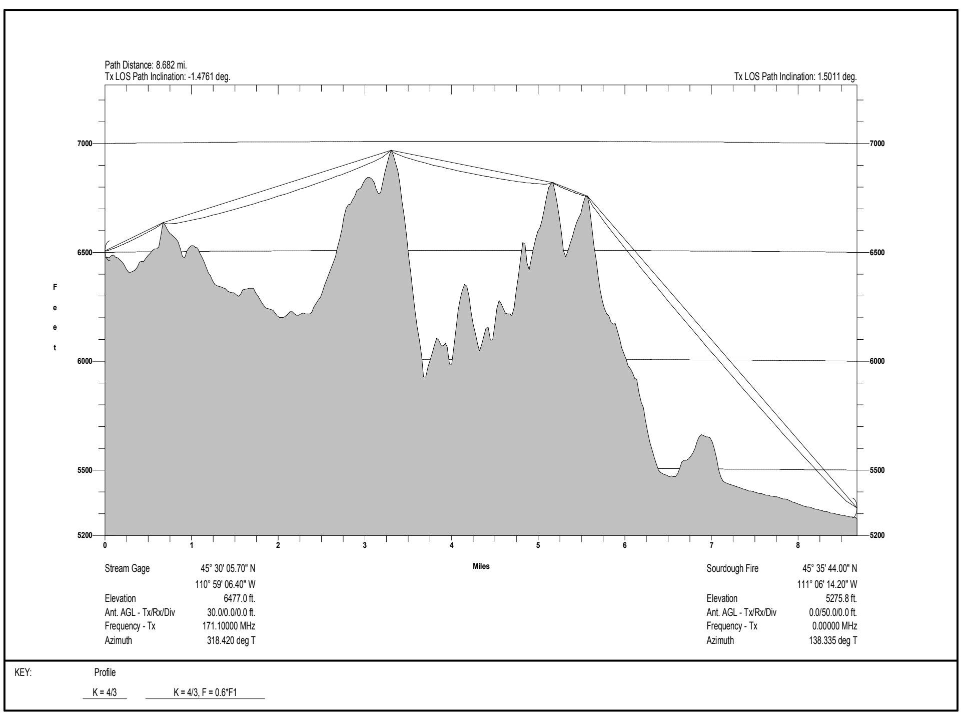

Path Distance: 20.313 mi.
Tx LOS Path Inclination: 1.8234 deg.
Tx LOS Path Inclination: -1.7994 deg.
Feet
Miles
Stream Gage
45° 30' 05.70" N
110° 59' 06.40" W
Elevation 6477.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 199.596 deg T
Eagle Head
45° 13' 27.84" N
111° 07' 28.92" W
Elevation 9846.3 ft.
Ant. AGL - Tx/Rx/Div 0.0/75.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 019.496 deg T
KEY:
Profile
K = 4/3
K = 4/3, F = 0.6*F1


Path Distance: 13.153 mi.
Tx LOS Path Inclination: -1.3911 deg.
Tx LOS Path Inclination: 1.4076 deg.
Feet
Miles
Stream Gage
45° 30' 05.70" N
110° 59' 06.40" W
Elevation 6477.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 349.785 deg T
EOC
45° 41' 20.40" N
111° 01' 59.88" W
Elevation 4770.6 ft.
Ant. AGL - Tx/Rx/Div 0.0/50.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 169.750 deg T
KEY:
Profile
K = 4/3
K = 4/3, F = 0.6*F1


Path Distance: 11.256 mi.
Tx LOS Path Inclination: -1.3283 deg.
Tx LOS Path Inclination: 1.3476 deg.
Feet
Miles
Stream Gage
45° 30' 05.70" N
110° 59' 06.40" W
Elevation 6477.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 350.043 deg T
Kenyon Water Tower
45° 39' 43.56" N
111° 01' 31.08" W
Elevation 5079.0 ft.
Ant. AGL - Tx/Rx/Div 0.0/50.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 170.014 deg T
KEY:
Profile
K = 4/3
K = 4/3, F = 0.6*F1


Path Distance: 12.439 mi.
Tx LOS Path Inclination: -1.4023 deg.
Tx LOS Path Inclination: 1.4198 deg.
Feet
Miles
Stream Gage
45° 30' 05.70" N
110° 59' 06.40" W
Elevation 6477.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 343.005 deg T
Law and Justice
45° 40' 25.68" N
111° 03' 36.72" W
Elevation 4849.3 ft.
Ant. AGL - Tx/Rx/Div 0.0/50.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 162.951 deg T
KEY:
Profile
K = 4/3
K = 4/3, F = 0.6*F1


Path Distance: 14.241 mi.
Tx LOS Path Inclination: -1.3024 deg.
Tx LOS Path Inclination: 1.3176 deg.
Feet
Miles
Stream Gage 45° 30' 05.70" N
110° 59' 06.40" W
Elevation 6477.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 340.450 deg T
New Dispatch 45° 41' 45.06" N
111° 05' 00.84" W
Elevation 4747.6 ft.
Ant. AGL - Tx/Rx/Div 0.0/50.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 160.380 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1


Path Distance: 8.682 mi.
Tx LOS Path Inclination: -1.4761 deg.
Tx LOS Path Inclination: 1.5011 deg.
Feet
Miles
Stream Gage 45° 30' 05.70" N
110° 59' 06.40" W
Elevation 6477.0 ft.
Ant. AGL - Tx/Rx/Div 30.0/0.0/0.0 ft.
Frequency - Tx 171.10000 MHz
Azimuth 318.420 deg T
Sourdough Fire 45° 35' 44.00" N
111° 06' 14.20" W
Elevation 5275.8 ft.
Ant. AGL - Tx/Rx/Div 0.0/50.0/0.0 ft.
Frequency - Tx 0.00000 MHz
Azimuth 138.335 deg T
KEY: Profile
K = 4/3
K = 4/3, F = 0.6*F1

Link Analysis Results

RF Communications Link Analysis

		Site A		**Site B**
Site Name	:	Middle Creek Dam		Bridger Ridge
Location	:			
Call Sign	:			
Latitude	:	45° 29' 21.30" N		45° 49' 00.70" N
Longitude	:	110° 58' 41.50" W		110° 55' 46.56" W
Elevation	ft/m:	6743.0 / 2055.3		8494.5 / 2589.1
Azimuth	deg:	5.921629		185.9564
Distance	mi/km:	22.75 / 36.6		22.75 / 36.6
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		75.0
Rx Antenna Type / Polarization	:	/ H		/ V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	108.38		63.72
Diffraction Loss	dB:	48.24		48.24
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	163.63		116.96
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-110.34		-112.66
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	-4.34		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Middle Creek Dam		High Flat
Location	:			
Call Sign	:			
Latitude	:	45° 29' 21.30" N		45° 38' 15.72" N
Longitude	:	110° 58' 41.50" W		111° 16' 04.08" W
Elevation	ft/m:	6743.0 / 2055.3		5633.5 / 1717.1
Azimuth	deg:	306.2221		126.0153
Distance	mi/km:	17.39 / 28.0		17.39 / 28.0
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		75.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	106.05		61.39
Diffraction Loss	dB:	39.2		39.2
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	152.25		105.59
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-98.96		-101.29
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	7.04		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Middle Creek Dam		Nixon Ridge
Location	:			
Call Sign	:			
Latitude	:	45° 29' 21.30" N		45° 57' 55.44" N
Longitude	:	110° 58' 41.50" W		111° 20' 18.60" W
Elevation	ft/m:	6743.0 / 2055.3		5646.6 / 1721.1
Azimuth	deg:	332.2057		151.9477
Distance	mi/km:	37.22 / 59.9		37.22 / 59.9
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		75.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	112.66		68.0
Diffraction Loss	dB:	28.05		28.05
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	147.71		101.05
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-94.42		-96.75
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	11.58		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Middle Creek Dam		Timberline
Location	:			
Call Sign	:			
Latitude	:	45° 29' 21.30" N		45° 38' 53.88" N
Longitude	:	110° 58' 41.50" W		110° 47' 48.84" W
Elevation	ft/m:	6743.0 / 2055.3		6417.6 / 1956.1
Azimuth	deg:	38.61696		218.7464
Distance	mi/km:	14.07 / 22.6		14.07 / 22.6
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		75.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	104.21		59.55
Diffraction Loss	dB:	48.07		48.07
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	159.28		112.62
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-105.99		-108.32
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	0.01		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Middle Creek Dam		Eagle Head
Location	:			
Call Sign	:			
Latitude	:	45° 29' 21.30" N		45° 13' 27.84" N
Longitude	:	110° 58' 41.50" W		111° 07' 28.92" W
Elevation	ft/m:	6743.0 / 2055.3		9846.3 / 3001.1
Azimuth	deg:	201.3585		21.25422
Distance	mi/km:	19.63 / 31.6		19.63 / 31.6
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		75.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	107.11		62.44
Diffraction Loss	dB:	37.01		37.01
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	151.12		104.45
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-97.83		-100.15
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	8.17		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Middle Creek Dam		EOC
Location	:			
Call Sign	:			
Latitude	:	45° 29' 21.30" N		45° 41' 20.40" N
Longitude	:	110° 58' 41.50" W		111° 01' 59.88" W
Elevation	ft/m:	6743.0 / 2055.3		4770.6 / 1454.1
Azimuth	deg:	349.0573		169.0179
Distance	mi/km:	14.05 / 22.6		14.05 / 22.6
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		50.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	104.2		59.54
Diffraction Loss	dB:	26.65		26.65
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	137.85		91.19
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-84.56		-86.89
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	21.44		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Middle Creek Dam		Kenyon Water Tower
Location	:			
Call Sign	:			
Latitude	:	45° 29' 21.30" N		45° 39' 43.56" N
Longitude	:	110° 58' 41.50" W		111° 01' 31.08" W
Elevation	ft/m:	6743.0 / 2055.3		5079.0 / 1548.1
Azimuth	deg:	349.1818		169.1481
Distance	mi/km:	12.15 / 19.6		12.15 / 19.6
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		50.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	102.94		58.28
Diffraction Loss	dB:	37.11		37.11
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	147.05		100.38
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-93.76		-96.08
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	12.24		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Middle Creek Dam		Law and Justice
Location	:			
Call Sign	:			
Latitude	:	45° 29' 21.30" N		45° 40' 25.68" N
Longitude	:	110° 58' 41.50" W		111° 03' 36.72" W
Elevation	ft/m:	6743.0 / 2055.3		4849.3 / 1478.1
Azimuth	deg:	342.6993		162.6407
Distance	mi/km:	13.35 / 21.5		13.35 / 21.5
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		50.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	103.76		59.09
Diffraction Loss	dB:	27.81		27.81
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	138.57		91.9
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-85.28		-87.6
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	20.72		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Middle Creek Dam		New Dispatch
Location	:			
Call Sign	:			
Latitude	:	45° 29' 21.30" N		45° 41' 45.06" N
Longitude	:	110° 58' 41.50" W		111° 05' 00.84" W
Elevation	ft/m:	6743.0 / 2055.3		4747.6 / 1447.1
Azimuth	deg:	340.3358		160.2605
Distance	mi/km:	15.16 / 24.4		15.16 / 24.4
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		50.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	104.86		60.19
Diffraction Loss	dB:	38.13		38.13
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	149.99		103.32
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-96.7		-99.02
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	9.3		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Middle Creek Dam		Sourdough Fire
Location	:			
Call Sign	:			
Latitude	:	45° 29' 21.30" N		45° 35' 44.00" N
Longitude	:	110° 58' 41.50" W		111° 06' 14.20" W
Elevation	ft/m:	6743.0 / 2055.3		5275.8 / 1608.1
Azimuth	deg:	320.3095		140.2198
Distance	mi/km:	9.55 / 15.4		9.55 / 15.4
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		50.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	100.84		56.18
Diffraction Loss	dB:	48.94		48.94
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	156.79		110.12
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-103.5		-105.82
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	2.5		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Stream Gage		Bridger Ridge
Location	:			
Call Sign	:			
Latitude	:	45° 30' 05.70" N		45° 49' 00.70" N
Longitude	:	110° 59' 06.40" W		110° 55' 46.56" W
Elevation	ft/m:	6477.0 / 1974.2		8494.5 / 2589.1
Azimuth	deg:	7.018824		187.0585
Distance	mi/km:	21.94 / 35.3		21.94 / 35.3
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		75.0
Rx Antenna Type / Polarization	:	/ H		/ V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	108.07		63.41
Diffraction Loss	dB:	55.71		55.71
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	170.78		124.12
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-117.49		-119.82
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	-11.49		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Stream Gage		High Flat
Location	:			
Call Sign	:			
Latitude	:	45° 30' 05.70" N		45° 38' 15.72" N
Longitude	:	110° 59' 06.40" W		111° 16' 04.08" W
Elevation	ft/m:	6477.0 / 1974.2		5633.5 / 1717.1
Azimuth	deg:	304.5329		124.3311
Distance	mi/km:	16.63 / 26.8		16.63 / 26.8
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		75.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	105.66		61.0
Diffraction Loss	dB:	23.31		23.31
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	135.97		89.3
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-82.68		-85.0
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	23.32		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Stream Gage		Nixon Ridge
Location	:			
Call Sign	:			
Latitude	:	45° 30' 05.70" N		45° 57' 55.44" N
Longitude	:	110° 59' 06.40" W		111° 20' 18.60" W
Elevation	ft/m:	6477.0 / 1974.2		5646.6 / 1721.1
Azimuth	deg:	332.0429		151.7898
Distance	mi/km:	36.31 / 58.4		36.31 / 58.4
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		75.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	112.45		67.78
Diffraction Loss	dB:	43.41		43.41
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	162.86		116.19
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-109.57		-111.89
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	-3.57		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Stream Gage		Timberline
Location	:			
Call Sign	:			
Latitude	:	45° 30' 05.70" N		45° 38' 53.88" N
Longitude	:	110° 59' 06.40" W		110° 47' 48.84" W
Elevation	ft/m:	6477.0 / 1974.2		6417.6 / 1956.1
Azimuth	deg:	41.94982		222.0842
Distance	mi/km:	13.64 / 21.9		13.64 / 21.9
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		75.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	103.94		59.28
Diffraction Loss	dB:	59.79		59.79
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	170.73		124.06
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-117.44		-119.76
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	-11.44		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Stream Gage		Eagle Head
Location	:			
Call Sign	:			
Latitude	:	45° 30' 05.70" N		45° 13' 27.84" N
Longitude	:	110° 59' 06.40" W		111° 07' 28.92" W
Elevation	ft/m:	6477.0 / 1974.2		9846.3 / 3001.2
Azimuth	deg:	199.5958		19.49648
Distance	mi/km:	20.31 / 32.7		20.31 / 32.7
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		75.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	107.4		62.74
Diffraction Loss	dB:	71.51		71.51
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	185.92		139.25
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-132.63		-134.95
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	-26.63		0.0

RF Communications Link Analysis

		Site A		**Site B**
Site Name	:	Stream Gage		EOC
Location	:			
Call Sign	:			
Latitude	:	45° 30' 05.70" N		45° 41' 20.40" N
Longitude	:	110° 59' 06.40" W		111° 01' 59.88" W
Elevation	ft/m:	6477.0 / 1974.2		4770.6 / 1454.1
Azimuth	deg:	349.7847		169.7503
Distance	mi/km:	13.15 / 21.2		13.15 / 21.2
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		50.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	103.63		58.96
Diffraction Loss	dB:	41.98		41.98
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	152.61		105.94
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-99.32		-101.64
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	6.68		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Stream Gage		Kenyon Water Tower
Location	:			
Call Sign	:			
Latitude	:	45° 30' 05.70" N		45° 39' 43.56" N
Longitude	:	110° 59' 06.40" W		111° 01' 31.08" W
Elevation	ft/m:	6477.0 / 1974.2		5079.0 / 1548.1
Azimuth	deg:	350.0426		170.0139
Distance	mi/km:	11.26 / 18.1		11.26 / 18.1
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		50.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	102.27		57.61
Diffraction Loss	dB:	45.18		45.18
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	154.46		107.79
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-101.17		-103.49
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	4.83		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Stream Gage		Law and Justice
Location	:			
Call Sign	:			
Latitude	:	45° 30' 05.70" N		45° 40' 25.68" N
Longitude	:	110° 59' 06.40" W		111° 03' 36.72" W
Elevation	ft/m:	6477.0 / 1974.2		4849.3 / 1478.1
Azimuth	deg:	343.0049		162.9513
Distance	mi/km:	12.44 / 20.0		12.44 / 20.0
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		50.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	103.14		58.48
Diffraction Loss	dB:	42.82		42.82
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	152.96		106.29
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-99.67		-101.99
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	6.33		0.0

RF Communications Link Analysis

		Site A		Site B
Site Name	:	Stream Gage		New Dispatch
Location	:			
Call Sign	:			
Latitude	:	45° 30' 05.70" N		45° 41' 45.06" N
Longitude	:	110° 59' 06.40" W		111° 05' 00.84" W
Elevation	ft/m:	6477.0 / 1974.2		4747.6 / 1447.1
Azimuth	deg:	340.4504		160.38
Distance	mi/km:	14.24 / 22.9		14.24 / 22.9
Frequency	MHz:	171.10000		0.00000
Equipment	:			
Tx Antenna Height	ft:	30.0		0.0
Tx Antenna Type / Polarization	:	Omni / V		/ H
Tx Transmission Line Length	ft:	0.0		0.0
Tx Transmission Line Type	:			
Rx Antenna Height	ft:	0.0		50.0
Rx Antenna Type / Polarization	:	/ H		Omni / V
Rx Transmission Line Length	ft:	0.0		0.0
Rx Transmission Line Type	:			
ERP / EIRP	dBm:	15.81 / 41.99		0.0 / 0.0
System Gains		**Site A to B**		**Site B to A**
Tx Antenna Gain	dBd:	6.00	dBd:	0.00
Tx Antenna Gain Adjustment	dBi:	2.15		2.15
Rx Antenna Gain	dBd:	6.00	dBd:	0.00
Rx Antenna Gain Adjustment	dBi:	2.15		2.15
Transmitter Power	dBm:	37.0		0.0
Total System Gain	dB:	53.29		4.3
System Losses		**Site A to B**		**Site B to A**
Free Space Path Loss	dBi:	104.32		59.65
Diffraction Loss	dB:	51.14		51.14
Foliage Loss	dB:	5.0		5.0
Tx Miscellaneous Loss	dB:	1.0		0.0
Rx Miscellaneous Loss	dB:	1.0		0.0
Total System Loss	dB:	162.46		115.79
Path Calculations		**Site A to B**		**Site B to A**
Unfaded Receive Signal Level	dBm:	-109.17		-111.49
Rx Threshold Level	dBm:	-106.0		0.0
Fade Margin	dB:	-3.17		0.0

Appendix B – Response to Comments Received from Review of the Draft Report

DNRC held two meetings with emergency response personnel and other interested parties after the initial interviews that were conducted by the consultant. Written comments were received from the following individuals and emergency responders in Gallatin County:

1. Doug Galarus
2. Richard Wolff
3. Kandy Rose
4. Jim Cashell Gallatin County Sheriff
5. Brett Waters Fire Chief, Central Valley Fire District and City of Belgrade Fire Dept.
6. Brian Crandall Fire Chief, Rae and Sourdough Fire Departments

Each of the comments has been considered and addressed, either by incorporating the suggestion into the final report, or by responding to the comment.

A general note to the comments addressed in this letter: The scope of this study is to evaluate the feasibility and probable cost of installing an early warning system (EWS) at Middle Creek Dam. Several responses to the provided comments state 'will be incorporated in final design' or 'further refined in final design'. These are appropriate statements for the comments being addressed. However, at this time, we are not proceeding with a final design, nor do we have funds available. Should it be deemed necessary to have an EWS at the Middle Creek Project, system ownership and operations and maintenance issues must be resolved. Possible sources of funding include municipal dollars, both County and City, grants obtained through the next legislative session, and private sources. The DNRC is committed towards upgrading the instrumentation at the dam to allow automated measurement and remote monitoring. Our current funding efforts are directed to that end.

Comments from Doug Galarus

Hello Rob.

Below, find my comments regarding the "Middle Creek Early Warning System Feasibility Study." As a homeowner of one of the first houses at the mouth of Hyalite Canyon, I am quite interested in the success of this project and commend you for your efforts.

The consultants have done a good job of analyzing the problem, including portions that are not within their scope. That is a testament to their recognition that the solution to this entire problem is a larger system rather than an isolated component / sub-system - i.e., detection and transmission. With that said, it is important that this document be interpreted for what it is - a feasibility study of that particular sub-system. And, although recommendations and designs are presented, I hope that you will consider that these recommendations and designs are not necessarily complete, because there is incomplete information about the large system and associated problem. The further workings of the entire system or process for notification of citizens such as me and my family and, of particular importance, the recommended action that we take upon notification are yet to be determined

In both meetings I've attended (Cottonwood Fire Station and Gallatin County Fairgrounds), I have expressed concern about the assumption/requirement that notification passes through local public safety officials - Sheriff's Department and Dispatch. This concern is expressed for a very simple reason: Given 30 minutes from failure of the dam to inundation of my home, every minute and second is precious. If it takes even as little as an extra minute for notification to go through an intermediary, that minute may be the difference between life and death for my family. Consider that it may take 5 to 10 minutes at best to gather my wife, baby, and elderly father into our vehicle. From there, it may take another 5 minutes to drive to safe ground. Again, every minute and second is precious. I do realize that it may not be feasible or reliable to have direct notification. However, that option should be considered until ruled out of consideration for very good reason.

DNRC Response: Notification of affected residents is the responsibility of the emergency response personnel in Gallatin County. Gallatin County has a variety of notification methods available to them including reverse-911, phone trees, and personal contact by emergency officials. It may also be feasible for Gallatin County to rebroadcast a failure notification signal within the Gallatin Valley that can be received by individuals with the appropriate radio equipment. A cost-item was added to the draft report for a repeater. The final decision regarding this capability, and the system details will be further refined in final design.

WET Response: The VHF radio-based architecture presented as one option in the study employs a broadcast protocol called Automated Local Evaluation in Real-Time (ALERT). This protocol was developed by the National Weather Service for specific applications in flood warning. The protocol is non-proprietary and a number of vendors make equipment to meet the specifications of ALERT. Under this architecture, the remote monitoring stations at Middle Creek Dam and at the stream gage on Hyalite Creek will assess the current hydrologic conditions and transmit a radio message when conditions meet the criteria for dam failure. Since ALERT is a distributed, broadcast protocol, any location in the radio coverage area that has a receiving antenna can pickup the signal. Currently, the feasibility study has identified the County's High Flat radio tower and the County EOC as potentially having reliable radio coverage directly from the remote stations (without the need for an intermediate radio repeater). This assumption must be confirmed by a field study during the final design. The feasibility study additionally included a repeater at the High Flat tower to re-broadcast the radio signal. This would extend the radio coverage area so that additional locations within the Gallatin Valley could also receive the signal directly. The feasibility study does not include costs for additional locations to procure and install the equipment required to receive the signal.

What appears absent from this process is a formulation and specification of system requirements for all stakeholders - public safety officials and residents alike. These requirements will be the necessary criteria for the successful solicitation, procurement, installation and maintenance of this sub-system and the greater system. One rule of successful requirements analysis is that you state "what" but not "how." You are diving deep into "how" before knowing all of the "whats." For a feasibility study, that is ok. For a system design and procurement plan, it is a fatal flaw. I assume you will have a detailed requirements document prior to proceeding with final system design and procurement.

DNRC Response: The specific requirements of the system will be addressed during final design.

With such cautions recognized, if the plan is to proceed ASAP with the procurement and installation of the detection and warning system, as outlined in the study, it is imperative that you build flexibility into this system. In other words, make sure that the system is extensible and non-proprietary. For instance, make sure that you are not locking yourself, and us, into a black box that cannot be adapted to meet subsequent identified requirements. I have seen this happen too many times, and the result is a system that soon doesn't work and needs to be replaced sooner than planned.

DNRC Response: The ALERT protocol that is recommended for the VHF option is widely utilized throughout the country for flood warning and is not proprietary. The alternative that utilizes OneRain is proprietary, but greatly reduces the requirements for local expertise in radio-frequency communications, programming, and interfacing with emergency response communications systems. The decision between the two alternatives will depend, in part, upon the resources and capabilities of the agency that is responsible for the long-term maintenance of the system. The individual system components will be specified during final design. DNRC agrees that it is desirable to utilize commonly utilized, non-proprietary equipment when appropriate.

WET Response: We concur with the notion that the final system should be flexible, extensible, and based on non-proprietary equipment and telemetry protocols (see our response to the first question above).

Enough of the big picture stuff. Here are some more specific comments:

It struck me that as part of this system, video monitoring might be useful. This would not have to be full streaming video, but frames sent every several seconds or so. This would greatly increase the communications requirements for the system, but might also greatly improve its utility.

DNRC Response: DNRC recognizes the benefit of video or photo monitoring. Such a system can be useful for both site security and for visual monitoring of site conditions. DNRC has installed such a system at one other site, but is not considering this as a potential element of the early warning system. The early warning system has been conceptualized to be as simple as is practical to increase it's reliability. DNRC does not currently have plans to install video monitoring at Middle Creek Dam. If such a system were installed, it would be independent from the early warning system.

WET Response: The VHF radio option employing the ALERT protocol can not handle transmission of video or photos. The protocol utilizes a 4 byte message to encode sensor and hydrologic information. The protocol is purposefully simple. The National Weather Service has determined through experience that a simple protocol remains reliable when conditions deteriorate. In past catastrophic events, such as the hurricanes experienced on the east coast, it was the simple telemetry systems such as ALERT that continued to function. Complex system, including video streaming and cellular-based systems failed during those events.

Page 5 of the report points out that the dam tender or casual observer cannot communicate observed problems due to communications limitations, chiefly cellular. Yet nothing is mentioned to improve that situation. In the meetings, the possibility for a QWest line was raised in cooperation with the Forest Service. Whether this or an alternate means be used, having a call-box or the like might be very helpful for this and other situations. In conjunction with video monitoring that I mention, you might "detect" the pending situation before failure.

DNRC Response: DNRC recognizes the benefits of a land-line. It would be beneficial for both embankment instrumentation as well as communication. A land-line is not considered to be a desirable option for an early warning system (please see the Telemetry System Alternatives section of the report). Qwest was contacted in 2005 and the estimated cost for a land-line at that time was $285,000. DNRC does not plan to install a land-line due to the high cost.

On Page 8, the mention of evacuation time as whatever time is left over troubles me. While I realize that may be the reality, someone needs to account for the realistic time needed to evacuate and build that into the requirements. See my comments above regarding time for my family to evacuate. Note too that the 8 minutes stated as response time to first household at mouth of canyon is a huge portion of the 30 minute time frame. If that could be eliminated, it could be the difference in life or death for my family. If it takes 10 minutes for a family to evacuate, then it is a requirement that the system provide notification within less than 20 minutes following the occurrence.

DNRC Response: The initial response time to the first household will depend upon the notification procedure that Emergency Response Personnel choose to utilize. The time available to evacuate the area at the canyon mouth will, however, remain very minimal regardless of the notification method.

Principals 11, 12 and 15 on page 12 are quite bold and are, thankfully, not held as absolutes through the remainder of the report. Please don't hold these principals as absolute.

DNRC Response: These guidelines are in reference to the following:

11. ***USBR does not use local radio telemetry systems***
12. ***USBR does not use sirens for notification***
15. ***USBR does not directly notify the public***

These are guidelines based upon the cumulative experience of the U.S. Bureau of Reclamation over many years at a number of different sites. It is very important that

this experience not be trivialized when designing an Early Warning System – particularly since early warning systems are not commonly utilized in the dam safety community as a risk reduction tool. USBR has more experience with the design and installation of dam failure early warning systems than any other public agency or private firm. If, for instance, VHF radio telemetry or a siren notification system is used, it must be recognized that the system will require dedicated personnel and budget for its continued operation. The feasibility report does not recommend the use of sirens, and does not recommend direct notification of the public. Radio telemetry is a viable alternative <u>if</u> dedicated funds are set-aside for its continued maintenance. The final decisions regarding system configuration will be made by the agencies responsible for the installation and ongoing operation and maintenance of the early warning system.

WET Response: We must respect the operational experience offered by the USBR. They have designed, installed, and maintained early warning and dam failure monitoring systems for the past 40 years (since the early 1970's). They have experience with multiple telemetry architectures and monitoring systems. If a local VHF-based system is determined to be the best solution for Middle Creek, the experience offered by the USBR should be considered in the design process. It may be possible to design the final system to avoid some of the problems experienced by the USBR on similar systems.

The latency values on page 20 seem odd, particularly for VHF and Cellular/Land-line. I don't see where the 11 minutes figure comes from for VHF, let alone the minutes figure for cellular. Both should be seconds.

WET Response: The 11 minute number originally came from Table 6 which showed the latency associated with a typical Campbell two-way radio telemetry system to query data from 20 stations. Table 6 has since been modified to show the latency to query data from 2 stations which is a more realistic number of stations for the Middle Creek monitoring network. The latency associated with two-way VHF/UHF radio and cellular/landline phone are on the order of 1 minute to query information from two stations. Because these telemetry options are based upon two-way communications, time is required to make a connection and to establish the "hand-shaking" between the polling location and the remote station. Once the connection is established and the "hand-shaking" is complete, the polling location must request data since its last connection. Data is transferred and confirmed and the connection is terminated. The same process is then followed to query data from the second station. This process can take as long as 30 seconds per station which translates to 1 minute to query data from two stations.

Page 24 identifies a Transportation Assistance Plan as being absent. This is a very important piece, although I realize it is outside the scope of this work. Consider elderly and other residents who would need help in evacuating.

DNRC Response: The notification and evacuation of the public is the responsibility of the local emergency response community.

Phone tree is mentioned on page 25 and elsewhere. While it is stated elsewhere, I have to say that it is obvious that a phone tree would fail in this sort of event. There would only be time to evacuate yourself and your family.

DNRC Response: DNRC agrees that there is limited time to initiate a phone tree, particularly in the areas that are further upstream. It is, however, still useful to have multiple means of notification and the phone tree may be of some utility both as a notification tool, and as a means of increasing public awareness.

Ford Response: We agree and acknowledge the limitations of the phone tree in table 13.

Telemetry System Design options 1 and 2 appear presented as alternatives rather than complementary systems. Redundant communications capability would be desirable.

DNRC Response: Only one alternative is recommended due to cost considerations.

WET Response: Redundancy is a critical aspect of the final design and must be incorporated. Redundancy will be achieved by using multiple stations/sensors, multiple radio links, multiple receiving locations, etc. Having multiple modes of telemetry would provide redundancy, the additional cost would be very high.

On Page 29, I would not call the associated computer a "dedicated PC workstation." The implication that this is a "PC" rather than a "monitoring station" or whatever better term can be applied might lead you to getting an actual PC, running Windows, with periodic reboots, blue screens, etc. That is not reliable enough for this application. Integration with the CAD system is mentioned too. This may be non-trivial, even beyond the point the consultants identified it as difficult. Please be cautious here about the complexity of integration issues.

WET Response: This is a good point. The report has been modified to replace the wording "PC workstation" with a dedicated terminal interface. The final form factor and ultimate configuration of the terminal interface will be determined in the final design.

Page 24 mentions "liability to DNRC and Gallatin County" and elsewhere a "paper trail" is mentioned. While these may be desirable to government entities, they don't sound good in this context. The primary goal is to save lives.

DNRC Response: The reference to "liability to DNRC …" has been reworded to better state the intended meaning - that the responsibility for operation and maintenance of the system would be shifted from Gallatin County to OneRain with that alternative. The paper trail is an important documentation tool that can be useful for troubleshooting the system and verifying that it is working as intended.

Page 33 presents what appear to be best guesses at reliability. Perhaps this is the best possible, but I would like to see more objective performance indicators used to back these values.

WET Response: Certainly the discussion concerning reliability found on Table 10 is subjective. It is founded upon general design principals and actual field experience brought to the project by civil and radio telemetry engineers at WET. The information

found in Table 10 does represent our best guess at reliability factors associated with various system components.

Note that on page 45, several instances of direct notification are described. Hopefully these will be considered. Again, in regard to the estimates and designs presented, treat these as examples and not as final. There may still be better or other options and not all requirements are known.

DNRC Response: The final system configuration will be delineated during final design.

Solar power is presented without discussion. It may be the only viable option, although grid power may be present in proximity to the dam. Regardless, the system should have battery backup, and that does not appear to be listed in the breakdown of costs. (There should be an associated requirement for duration of backup power.

WET Response: The system preliminary design is based upon remote stations that are battery powered with solar recharging. None of the stations identified is connected to grid power. The stations will typically be configured with 12 volt, 18 amp hour batteries and solar panels sized sufficiently large to keep the batteries charged during cloudy or winter periods. The final design will include battery storage and solar recharge computations to size both the battery and solar recharging components.

Note too that vandalism is not addressed in regard to the install options. It is noted earlier in regard to fixed signs. Vandalism should be a concern in this area and precautions such as appropriate fencing, etc. should be taken so-as to deter vandals.

DNRC Response: The potential for vandalism will be considered during final design with regards to component siting and configuration.

WET Response: The reduction of vandalism will be a requirement in the final design. Note that intrusion sensors have been included in the feasibility report. These would provide immediate notification to the County when an electronics enclosure has been compromised.

In general, again, the two options are presented in a somewhat odd fashion - distinguished by the communications link type. It might be better to break down the system into detection/sensors and communications. And, it would be useful to consider redundant communication systems.

DNRC Response: The two communication systems were chosen as separate alternatives because they differentiate between two distinct philosophies with the early warning system – the locally configured "radio telemetry" type system, and the more standardized satellite/internet system. The two alternatives are conceptually very different with unique advantages and disadvantages.

WET Response: The primary difference between the options is the communications or telemetry system. The detection/sensors remain consistent among various options and are therefore not a differentiator. Additionally the feasibility report tried to address the notification component which also differs between the two systems.

I have other smaller comments, but this is the bulk. I hope these comments help you. Again, I am very interested in the success of this effort and appreciate your efforts to help his. Please involve me in further review and comment. As a homeowner who would be immediately affected, I would like to assist in any way possible.

Best regards,

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Comments from Richard Wolff

December 18, 2007

Subject: Comments on the "Middle Creek Early Warning System Feasibility Study" draft report

Comments prepared by Richard S. Wolff, 420 Meadowlark Dr., Bozeman MT 59718. (406) 585 5490; rwolff@montana.edu

These comments are prepared as citizen response to the "Middle Creek Early Warning System Feasibility Study" draft report dated December 7. 2007. My comments address three issues: 1) event detection; 2) telemetry; 3) public notification.

1. Event detection. The report (page 1) notes that the charter of the study is to address items 2 and 3, but then goes on to discuss detection systems (pages 11-15). I have no expertise in this area and assume that the methods and design principles recommended by the U. S. Bureau of Reclamation are applicable.

DNRC Response: The report does discuss event detection, telemetry, and notification. The USBR design principals are based upon past experience and are considered to be applicable.

WET Response: The design principals offered by the USBR were taken into consideration in the preparation of the feasibility report but were not considered to be absolute.

2. Telemetry. The report conclusion, that a terrestrial UHF/VHF radio link would be the most cost effective an reliable approach is well founded. I would caution the DNRC to take the results given in the report as "illustrative", and not as a specific product recommendation. I suggest that the DNRC consider additional factors in selecting a particular UHF/VHF radio system, such as the use of open standards versus proprietary products, compatibility of the selected equipment with other equipment already in use by the county and other relevant agencies, the feasibility of sharing spare parts, maintenance and operational expertise already available.

DNRC Response: The ALERT based system is non-proprietary and is in common use throughout the country for flood warning systems. DNRC agrees that it is generally preferable to utilize non-proprietary equipment.

WET Response: Nothing in the feasibility report is presented as a specific product recommendation or endorsement. The ALERT radio telemetry protocol is an open, non-proprietary standard employed throughout the U.S. in the flood warning arena. We concur that the final design should consider compatibility with existing County equipment and maintenance and operational expertise available at the County.

The report is almost silent on the issue of powering the sensor and telemetry equipment. The cost of solar panels is included in table 14 (page 49), but there is no discussion of their use as primary versus backup power (e.g. is their an assumption of the availability of commercial power at the dam site?), or what their reliability might be. The issue of powering the remote equipment needs further examination.

WET Response: The system preliminary design is based upon remote stations that are battery powered with solar recharging. None of the stations identified is connected to grid power. The stations will typically be configured with 12 volt, 18 amp hour batteries and solar panels sized sufficiently large to keep the batteries charged during cloudy or winter periods. The final design will include battery storage and solar recharge computations to size both the battery and solar recharging components.

The report is quick to dismiss the use of land line telephone service (page 18). I suggest that further research be conducted to determine whether a local service provider (e.g., Qwest) has any plans to provide service in Hyalite Canyon, as telephone line could serve a good back up to the proposed telemetry system, providing added redundancy.

DNRC Response: Please see response to similar comment received from Doug Galarus.

3. Public notification. Pages 34 through 47 of the report address methods of public notification and provide some useful examples of similar situations (pages 45-46). This topic is separable from the telemetry system, and has wider scope, as a notification system should be considered in the context of other uses, such as wildfires and other disasters. The report notes that the public notification is the responsibility of the county and local response personnel. However, given the very short time interval between a dam failure and the arrival of the water at the mouth of the canyon (30 minutes) and Langohr Springs Campground (15 minutes) (data in Table 5, page 8), special consideration for this areas needs to be taken into account. As noted on pages 45 and 46, several warning systems incorporate a combination of techniques, including sirens in areas immediately downstream of the dam. The installation of sirens in the most vulnerable areas, such as Langohr Springs Campground and the mouth of Hyalite canyon should be examined, along with the feasibility of connecting the siren activation system directly to the sensor system to minimize the warning time delay. (Disclaimer: I offer these comments as resident of the area at the mouth of the canyon.)

DNRC Response: The notification system is separable from the other system components and is the responsibility of local emergency response personnel. The report determined that it is not feasible to provide advance warning at Langohr Campground – primarily due to the short travel-time. It would also be very difficult to inform campground users of appropriate evacuation routes. The report evaluated the use of sirens as a notification system and determined that they are currently not a recommended option due to the high installation and maintenance costs, their relative inability to be heard indoors, and the large number of sirens that would be required to provide coverage over the affected area.

Comments from Kandy Rose

While we have Neighborhood Networks throughout Sourdough Fire District, not all of our neighborhoods are in the inundation area. For example, while Triple Tree Ranch, Hodgeman Canyon and Mystic Heights each have a Neighborhood Network, they are not in the affected area (there is no Three Tree - maybe you got that from Triple Tree).

Also, not all of the affected area where we have Neighborhood Networks are at the base of the canyon. Some are in the 20-30 min inundation area at the base (like Forest Creek) - others are in the 30-60 min affected area) like Hyalite Meadow and Lazy TH) - further away. What we do share in common is that sooner or later, in the event of the breach of the dam, we would be in the inundation area.

Ford Response: Replaced "at the base of the canyon" with "residents of the Sourdough Fire District"

One of our firefighters is a mom who has a child at Anderson School. She works there and is chair of the Safety Committee as well. She carries a two-way radio with her at all times - as well as her pager. So, that's how that school has contact. The other school in the inundation area, Monfortton, does not. However it was that school that rallied a significant number of letters in support of the grant for this study.

Ford Response: Removed mention of all schools having two-way radio. Modified section "Middle Creek Stakeholder Opinions and Desires for Public Notification" per comment.

I've added and corrected some info below. Hope it helps. Please don't hesitate to contact me again if I can be of assistance. If not, best wishes for happy holidays to you and yours!

Kandy

Additional comments from Kandy Rose follow.

1. **Phone tree**. Residents living at the base of the canyon have formed a phone tree, called Neighborhood Networks, for notifying their neighborhood in emergencies. This has worked well for them during past events (fires). The Neighborhood Network is activated at the request of the local fire department.

Neighborhoods involved include the following:

- Forest Creek
- Hodgeman Canyon
- Hyalite Foothills
- Hyalite Meadow
- Lazy TH:
- Mystic Heights

- Triple Tree Ranch

Ford Response: Three Tree and Green Hills Ranch removed from report per these comments.

2. **2-way radio**. There are 6 families in Hyalite Meadow who live at the base of the canyon who carry 2-way radios for communication with their local fire district and each other in the event of an emergency. These families have been involved in CERT training for 5 years and continue to meet monthly to practice emergency/disaster skills.

Ford response: Modified 2-way radio information in report to incorporate these comments.

Comments from Jim Cashell, Brett Waters, and Brian Crandell

To: MT DNRC, Middle Creek (Hyalite) Dam Early Warning/Emergency Notification System Study Project

From: Jim Cashell, Gallatin County Sheriff

Brett M. Waters, Fire Chief, Central Valley Fire District and City of Belgrade Fire Department

Brian Crandell, Fire Chief, Rae and Sourdough Fire Departments

Date: 01-09-2008

Emergency responders responsible for the safety of citizens residing in the inundation area of Hyalite Dam (Middle Creek) met on January 7, 2008. The purpose of the meeting was to take a closer look at the completed study to assess its effectiveness to provide necessary warning of a breach of the dam.

The following conclusions are offered for your consideration:

1) MT DNRC as owner of the dam should formulate legislation for funding to pay the initial costs of design and construction of an early warning system on Hyalite (Middle Creek) dam that would incorporate the use of a VHF/UHF radio system. This proposal would be strongly supported by emergency responders.

DNRC Response: As owner of the dam, DNRC is responsible for monitoring the performance of the dam and insuring that it is in compliance with current dam safety standards. This is the most effective means of maintaining the integrity of the dam and protecting the safety of the downstream residents. DNRC recognizes that there is much support for an early warning system within Gallatin County and will support their efforts to obtain funding for such a system.

2) To ensure redundancy, signals from the warning system would be received at the following locations:

Gallatin County 911 Center

Gallatin County EOC

Anderson School

Monforton School

Cottonwood Fire Station

Central Valley Fire Station on Main Street in Belgrade

Bozeman Fire Department

Each of these receiving sites would be responsible for providing the equipment necessary to receive the signal from the system and process data.

DNRC Response: The feasibility study has been modified to include a cost item for a repeater to rebroadcast the signal so that it may be received at multiple locations within Bozeman-Belgrade area.

WET Response: Under the ALERT VHF architecture, the remote monitoring stations at Middle Creek Dam and at the stream gage on Hyalite Creek will assess the current hydrologic conditions and transmit a radio message when conditions meet the criteria for dam failure. Since ALERT is a distributed, broadcast protocol, any location in the radio coverage area that has a receiving antenna can pickup the signal. Currently, the feasibility study has identified the County's High Flat radio tower and the County EOC as potentially having reliable radio coverage directly from the remote stations (without the need for an intermediate radio repeater). This assumption must be confirmed by a field study during the final design. The feasibility study as additionally included a repeater at the High Flat tower to re-broadcast the radio signal. This would extend the radio coverage area so that additional locations within the Gallatin Valley could also receive the signal directly. The feasibility study does not include costs for additional locations to procure and install the equipment required to receive the signal.

3) Cost of maintenance of this system should be shared with the DNRC responsible for sensors and equipment at or near the dam site, and Gallatin County 911 Center responsible for the radio equipment used in the system.

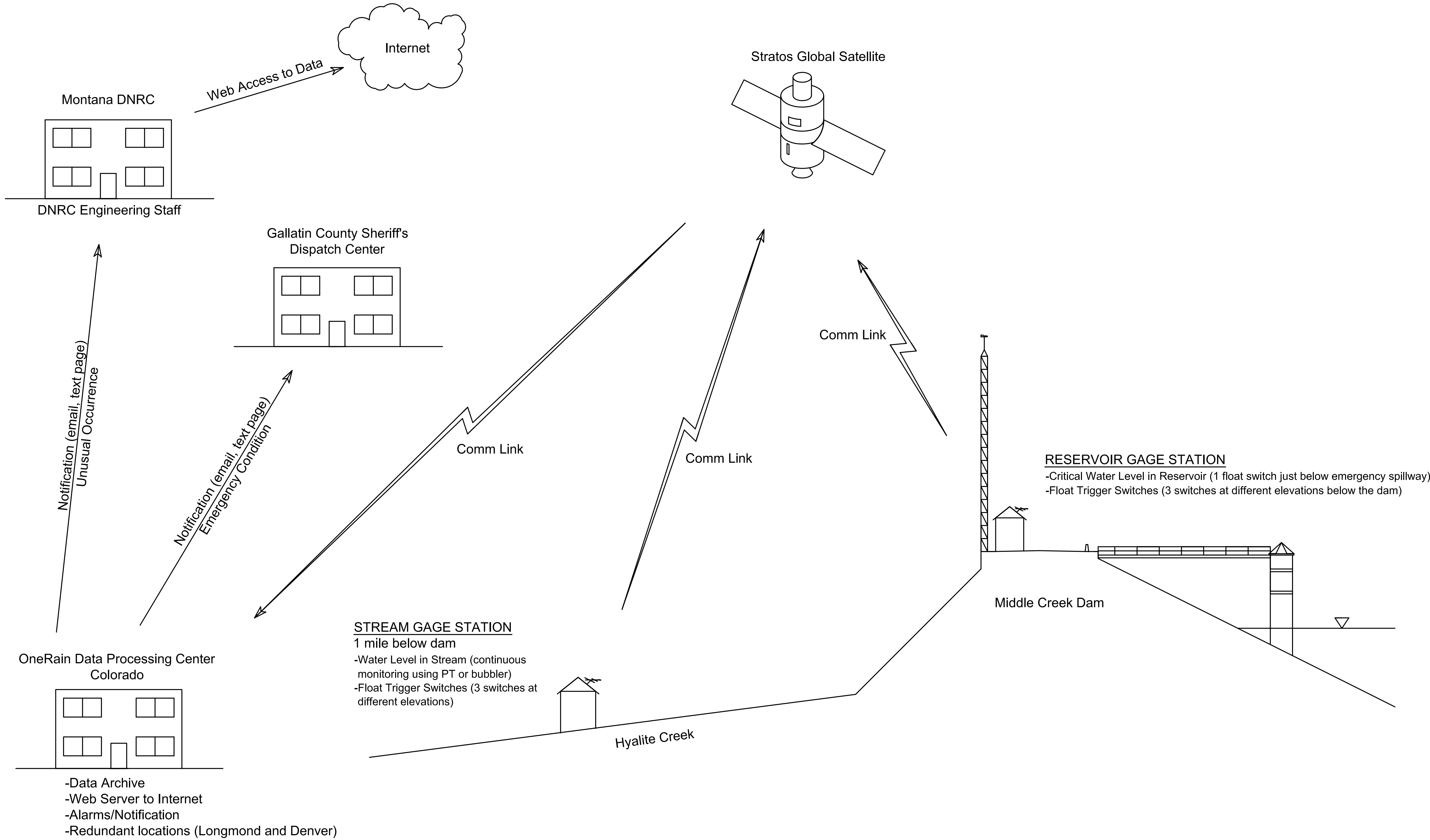
DNRC Response: To ensure reliability, it is undesirable to divide maintenance responsibilities for the system. The early warning system will likely be completely separate from instrumentation used for monitoring the project's performance, and should be maintained as such. The EWS will include a variety of elements that must interface with the Gallatin County radio and emergency dispatch systems. Periodic testing, maintenance, and system upgrades should be the responsibility of Gallatin County. The long-term viability of the system is dependent upon Gallatin County dedicating sufficient funds towards its ongoing operation. The feasibility Study provides an estimate of these anticipated operation costs. DNRC will assist Gallatin County with identifying potential funding sources for the initial installation of the system.

Thank you for allowing us to submit this input.

Drawings

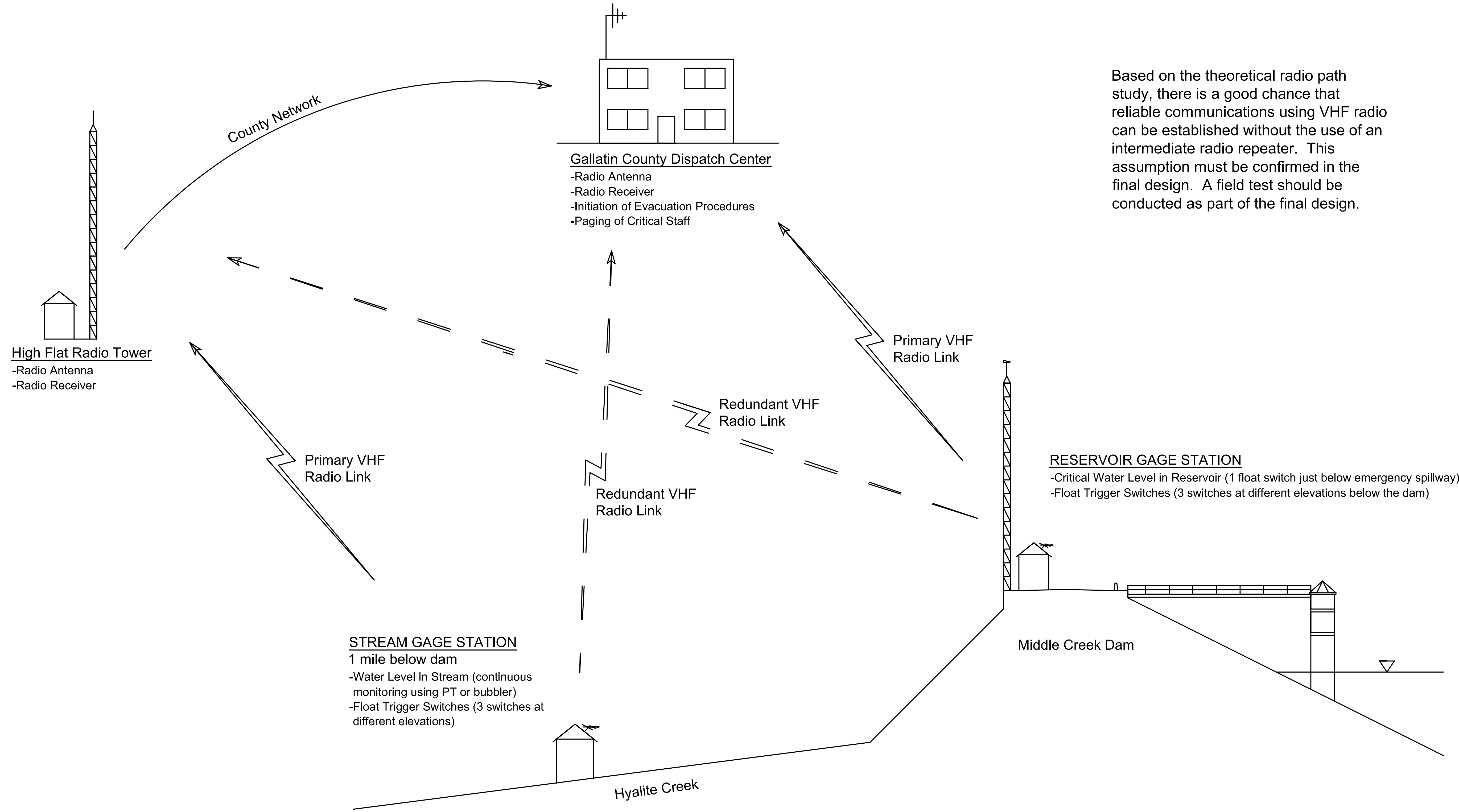
(Drawing 1) Middle Creek Dam Early Warning System Conceptual Plan, Option 1 – OneRain Storm Link Architecture

(Drawing 2) Middle Creek Dam Early Warning System Conceptual Plan, Option 2 – VHF ALERT Radio Architecture



FINAL	Project No: A288	Designed: MLR	Middle Creek Dam Early Warning System Conceptual Plan Option 1 - OneRain StormLink
NOT TO SCALE	Drawing: 1	Drawn: EEC	P:\A288-Middle_Crk_MT_DNRC\Drawings\AutoCAD2000\MC_DAM_Profile.dwg
	Date: 11/30/2007	Checked: MLR	

Water & Earth Technologies, Inc.
Water Resources and Environmental Consulting



Based on the theoretical radio path study, there is a good chance that reliable communications using VHF radio can be established without the use of an intermediate radio repeater. This assumption must be confirmed in the final design. A field test should be conducted as part of the final design.

FINAL	Project No: A288	Designed: MLR	Water & Earth Technologies, Inc. Water Resources and Environmental Consulting	Middle Creek Dam Early Warning System Conceptual Plan Option 2 - VHF Radio
	Drawing: 2	Drawn: EEC		
NOT TO SCALE	Date: 11/30/2007	Checked: MLR		P:\A288-Middle_Crk_MT_DNRC\Drawings\AutoCAD2000\MC_DAM_Profile_2.dwg