Flood Monitoring System Assessment & Improvement Plan Development Report

Submitted by AMR Consults, LLC to the Upper Brushy Creek Water Control and Improvement District

February 5, 2013

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Table of Contents

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Background and Purpose

One of the primary missions of the Upper Brushy Creek Water Control and Improvement District (UBCWCID) is to operate and maintain the system of 23 flood retarding dams and reservoirs in the Upper Brushy Creek watershed, which were constructed by the United States Natural Resources Conservation Service (NRCS, previously known as the U.S. Soil Conservation Service, or SCS) in the late 1950's to the mid 1960's. Changes in state dam safety regulations necessitated a modernization program to protect the dams from breaching during the Probable Maximum Flood (PMF). The District and state regulators then agreed that implementing a network of automatic monitoring sites at the 21 high hazard dams would allow the dam physical improvement requirements to be relaxed (it should be noted that the District did proceed with a program to design and retrofit the high hazard dams to survive the 100% PMF, and construction has been completed at 19 of the 21 sites to date). This Flood Monitoring System (FMS) has been in use by the District since 2005, allowing District staff to monitor precipitation and reservoir water levels remotely, allowing simple forecasting of conditions which could impact dam performance, along with presentation of the gauge data on a District website for general public use (http://www.ubcwcid.org/Overview/Overview.aspx).

The District is entirely within Williamson County in Central Texas, and the basin area served by the District is approximately 192 sq. mi., and includes the headwaters of the Brushy Creek watershed, which ultimately drains into the Gulf of Mexico through the Brazos River. The local climate is home to significant rainfall events, with multiple global rainfall records occurring within 150 miles of the District. When coupled with the extreme rainfall rates, steep rocky terrain has helped the region earn the dubious title of "Flash Flood Alley". The area has also been home to one of the highest growth rates in the US in recent years, potentially placing large populations at risk from flooding.

After operating the FMS for 7 years, the District solicited external guidance to evaluate if there were opportunities to enhance the performance of the FMS, along with any potential reductions in the maintenance cost of the system. AMR Consults, LLC (AMR) was selected to perform an assessment of the existing FMS, and to make recommendations for the future of the system. The AMR team also included Distinctive AFWS Designs, Inc. (DAFWSD) and WEST Consultants, Inc. (WEST).

Sensing Hardware Assessment

A site visit was performed on the morning of 12-19-2012, with a visual inspection of the equipment at site 2 (photos in Appendix B). The original scope called for visits to each of the 21 FMS field sites (layouts of each of the individual sites can be seen in Exhibits 3-23, in Appendix A), but the District and AMR agreed that as a cost saving approach,

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the findings from site 2 (and the brief visit to site 1 that same morning, which appeared quite similar to site 2) could be assumed representative for all 21 sites. The site 2 visit was concurrent with the initial site maintenance visit by staff from High Sierra Electronics (HSE). Initial observations indicated that the site installation was ruggedly designed and constructed, but there were some elements which did not appear to be implemented in a manner conducive to accurate measurements and ease of maintenance. Each of the individual sensor types are described below, along with assessments of their functionalities.

Precipitation is measured with what was appeared to be a High Sierra Electronics (HSE) model 2400 (as listed in specifications documentation, provided by David Counts – Automated Concepts, Inc. (ACI), with a 1 mm tipping bucket, according to transmitted data), inside of a 12" standpipe and top section. The standpipe was mounted at the crest of the dam, with sloping embankments on both sides of the dam (see photos in Appendix B, page 39). The adjacent vicinity was clear of vegetation, and the only obstruction within 45° of vertical from the tipping bucket was the FMS antenna and pole. The top section was also fitted with vertical wires, as a bird deterrent. The tipping bucket arrangement appeared to be within accepted norms for flood monitoring purposes, and when properly maintained should be capable of providing measurements appropriate for the local high intensity precipitation environment.

From a basin-wide precipitation gauging perspective, there are 21 FMS precipitation gauging sites in the Brushy Creek basin that drains through the District boundary, with an average gauge density of 1 gauge per 9.1 sq/mi, which is sufficient to represent the precipitation variability that is common in Central Texas (a higher density than may be required in other regions, which do not experience small, intense convective thunderstorm activity). However, this gauge density is concentrated in some areas, with other areas not being well monitored (see Exhibit 1 in Appendix A, with 1 notable area in the north, central portion of the basin, where there are no gauges at dam sites 10A and 10B). Exhibit 24 (Appendix A) illustrates how precipitation measurements can be areally allocated for basin hydrologic modeling with the current gauge layout.

Water level measurements within the reservoir can be potentially obtained from 3 separate sensors. 2 Pressure Transducers (PTs) were mounted within the base of a vertical riser pipe (approximately 110' from the standpipe), installed at the approximate elevation of the primary spillway (referred to as the Design Conservation Pool elevation, refer to Table 1), with the 2 PTs separated approximately 0.5' vertically from each other. There was also a float switch installed within a concrete vault in the upstream face of the dam, designed to be at an elevation approximately 1' below the emergency spillway. The PTs and float switch were located approximately 1,070' from the primary spillway, and approximately 1,340' from the emergency spillway.

The mounting configuration for the PTs could potentially offer a redundant solution for reservoir level measurement, but the protective housing on the riser pipe was buried in mud, and the PTs were also encased in mud, which can have an impact on the measurements and maintenance. The PT vent tubes also appeared to have been pinched and cut before reaching the standpipe, with a desiccant pack and connections to the datalogger. Pinched vent tubes can cause barometric pressure variations to be introduced into the water level data. Cut vent tubes can allow water or humidity to enter the PTs, which can quickly destroy them. The float switch was difficult to inspect, as it was inside of an enclosure with a cast grating, which utilized theft proof fasteners (the District's only tool resides with the design engineer, who was not available during our site visit), all of which was also under a large bolted grate (mounted to the concrete vault). There were trash and debris captured in the vault, and it was assumed that the float enclosure may have also accumulated some sediment and/or debris, which could affect the open float.

Table 1 – FMS Sites General Data

			Data from Dams & Maps information webpages									*Addresses in FEMA Floodplain*		
	FMS Site	**Radio Path (mi)**	**Primary (MSL)**	**Emergency (MSL)**	**Crest (MSL)**	**Crest - Primary (ft)**	**Height (ft)**	**Length (ft)**	**Volume (ac-ft)**	**Drainage Area (sm)**	**100% PMF Protected**	**Upstream (Reservoir Pool)**	**Downstream (WCID)**	**Downstream (Williamson County)**
Dam 1	Y	12.2	1012.5	1025.9	1030.8	18.3	33	4,205	199	5.07	Y	1	282	307
Dam 2	Y	9.7	947.2	962.0	967.0	19.8	39	2,197	189	3.13	Y	6	268	293
Dam 3	Y	7.2	876.7	901.0	906.5	29.8	55	4,072	196	8.01	Y	1	268	293
Dam 4	Y	6.3	838.3	858.9	863.9	25.6	51	1,956	200	5.43	Y	5	252	277
Dam 5	Y	6.2	886.1	902.9	907.5	21.4	32	1,083	36	1.00	Y	0	266	291
Dam 6	Y	8.3	889.0	907.2	914.2	25.2	47	1,533	225	5.76	Y	18	246	271
Dam 7	Y	5.3	804.6	828.2	834.8	30.2	56	2,283	321	15.85	Planned	5	242	267
Dam 8	Y	6.0	826.4	846.8	881.8	55.4	46	2,290	262	8.39	Planned	1	448	473
Dam 9	Y	4.3	775.0	795.0	807.0	32.0	47	3,616	*4,260	4.79	Y	0	448	473
Dam 10A	n		815.0	834.7	841.1	26.1	42	1,556	81	4.18	n	0	228	253
Dam 10B	n		801.1	817.2	823.4	22.3	37	1,479	51	1.83	n	0	228	253
Dam 11	Y	0.4	725.2	737.1	743.6	18.4	40	2,427	374	15.37	Y	13	214	239
Dam 12	Y	1.5	768.0	782.3	787.3	19.3	31	4,930	104	2.83	Y	25	302	327
Dam 13A	Y	3.8	829.4	841.8	846.0	16.6	29	4,990	104	3.97	Y	19	240	265
Dam 14	Y	1.4	714.1	723.0	727.6	13.5	23	1,559	200	2.46	Y	28	212	237
Dam 15	Y	4.7	699.0	709.2	713.5	14.5	27	2,770	118	1.29	Y	0	189	214
Dam 16	Y	3.9	719.0	729.5	734.7	15.7	42	2,547	506	5.67	Y	1	185	210
Dam 17	Y	3.6	670.9	680.6	684.5	13.6	38	1,562	119	1.17	Y	0	195	220
Dam 18	Y	6.2	659.5	671.2	676.7	17.2	34	2,345	177	2.19	Y	0	168	193
Dam 19	Y	5.4	660.2	675.7	680.8	20.6	35	1,453	122	1.67	Y	2	181	206
Dam 20	Y	7.1	649.0	660.2	664.7	15.7	33	1,020	81	0.91	Y	4	172	197
Dam 21	Y	8.2	618.8	630.0	634.4	15.6	35	743	79	0.91	Y	1	107	132
Dam 22	Y	9.3	600.0	609.7	613.8	13.8	27	906	88	0.71	Y	1	109	134

* value posted on website is not correct

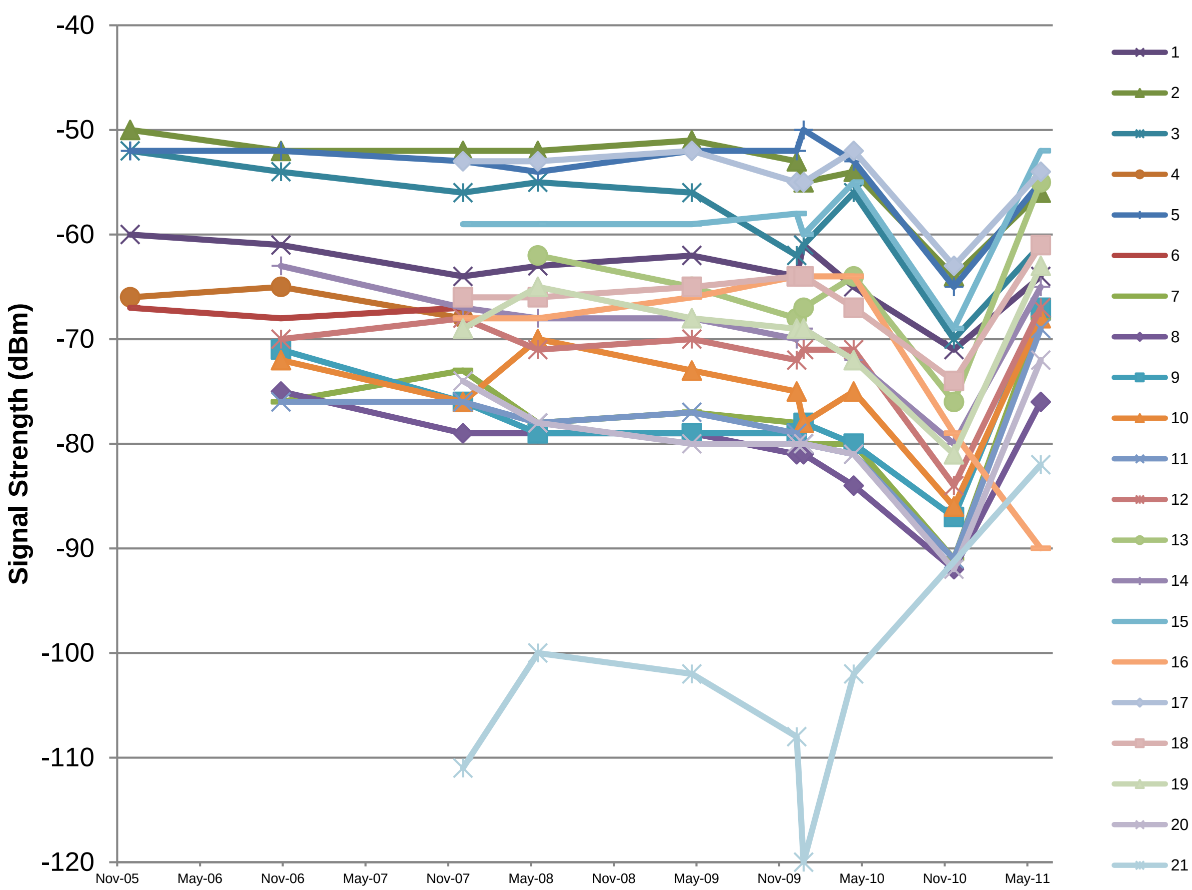
The PTs were being replaced by HSE during their initial maintenance visit to site 2, due to erroneous data, potentially due to the vent tube issues mentioned above. Upon further discussion, the District requested that HSE hold off with further PT installations, pending assessment of the recommendations from this report.

Communications Hardware Assessment

A site visit was performed on 12-10-2012 to the communications base station, located at the Round Rock Police Station. The FMS electronic equipment was housed in a concrete structure, directly underneath the large (300' estimated) tower (photos in Appendix B). Inside of the structure was a single rack panel, which contained all of the FMS electronic equipment. Communications between the Base Station and external users was the Internet, using a relatively low speed DSL connection (according to the District). The location was secure, had power conditioning and backup generation, and the antenna height, coupled with the antenna masts at each of the dam sites should allow adequate line of sight communications paths to the FMS sites (site 1 is the furthest, slightly more than 12 miles, averaging less than 6 miles for all sites). The telemetry appears to be via Opto-22 PLC dataloggers, communicating through MDS radios to a central base station, using Microwave Public Safety Pool frequencies (932.44375 MHz remote sites transmit and 941.44375 MHz base station transmit, according to the FCC license, which is valid through 08-11-2019). Data is collected remotely by the PLCs on a 5 minute interval, with data interrogated from the base station on a 15 minute interval.

A cursory review of the MS Access database(s) and other provided documentation provided by the District was conducted by DAFWSD. One of the data elements in the database is RSSI (Received Signal Strength Indication). The values come from each remote gauging station radio and are recorded with the site data every five minutes. The less negative the value the stronger the signal. Thus, an RSSI of -50 dBm represents a stronger received signal than -90 dBm; less is better. Figure 1 is a graph of periodic RSSI values from the 21 remote sites during the period of November 2005 thru August 2011. The RSSI for most of the gauging stations range between -50 and -80 dBm, which is very good and should be able to deliver quality reliable data between the remote stations and the base station.

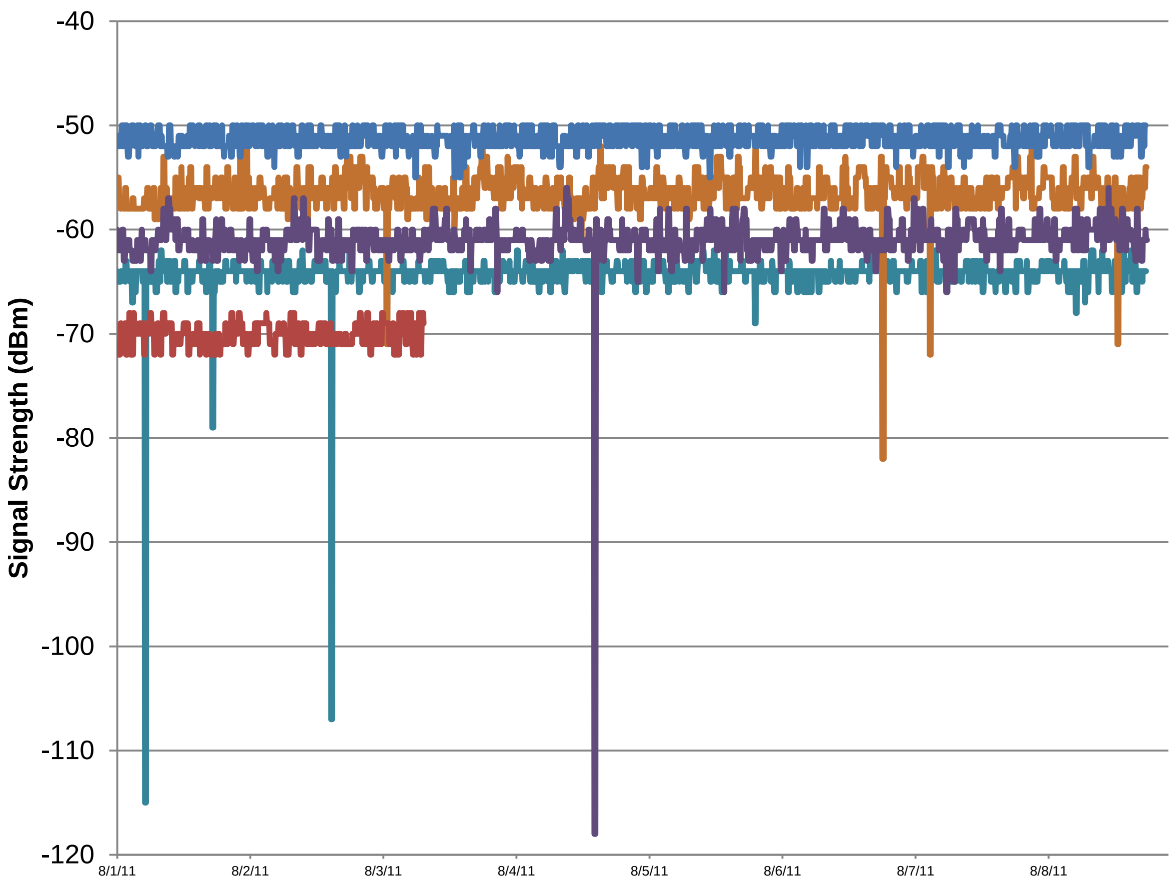
Figure 1 – RSSI Performance History



As evidenced by the dip in RSSI values in Figure 1, something happened in 2010 that caused significant degradation of the system (Tropical Storm Hermine passed through the District during September, 2010; it is possible there could have been residual impacts to communications from the storm). Then in late 2010 or early 2011 a change occurred that resulted in an improvement that was better than the suffered loss. The only site that appears to have been operating outside a most desirable Radio path is database ID 21 (field site 22). Prior to the improvement(s) in late 2010 or early 2011, this site has operated below –100 dBm. While stations can reliably operate in this range, they do not have the fade margin to survive degradation like what happened in 2010. Yet, the improvements made brought this site back close to the –80 dBm range. Perhaps some modification in system configuration can account for the signal changes during this period.

Figure 2 contains a graph of 5-minute RSSI values from 19 remote sites (IDs 4 and 6 were reporting values of "0" during period). The main thing to take away from this graph is all the negative spikes that are occurring at several of the sites.

Figure 2 – RSSI 8 Day Interval



Further review of random samples of data sets indicate that more than one remote site may be trying to communicate with the base station at the same time. This is causing data collisions and will result in increased channel loading due to the augmented retry efforts. The plot in Figure 2 only includes data from 5 sites, so there are likely many other negative values than are shown.

Based on a review of data for eleven days at the beginning of 2010, approximately 4% of the data reports were received with a latency greater than 15 minutes (which is the design poll cycle of the system). From that same data set, just over 1 % of the data is received more than 6 hours late. Almost half of those are from site 21, which has numerous latencies over 24 hours. This was during the period when site 21 had an RSSI between -100 and -115 dBm. It should be noted that the most data provided for this review was only thru August 2011, and current conditions may vary from this analysis.

Based upon the above analysis of RSSI data, the District and AMR agreed that onsite communications analysis could be avoided, as a cost saving measure.

Base Station Computing Assessment

The equipment for the original data communications, analysis, and web service implemented by ACI appears to consist of a rack-mount Dell PowerEdge 1950 (with currently unknown specifications for processors, RAM, or hard drive capacities), located in the base station communications shelter under the Round Rock Police Station radio tower (see photos in Appendix B). There is conditioned power, with a 1500 VA UPS in the rack and backup generation for the facility. Additional computing equipment was recently added to the rack for the Kisters WISKI application. This equipment consists of a Dell PowerEdge R420, with 2 Xeon E5-2440 (6 core) processors, 32 GB RAM, and 5 300 GB SCSI (15K RPM) hard drives (RAID 1 + RAID 5).

The software environment for the ACI system is not well documented, but appears to be custom applications, developed by ACI in a Windows Server environment. The WISKI system is a commercial off-the-shelf (COTS) water resources application, implemented by Kisters staff, and is running on a Windows 2008 server.

The ACI applications were not reviewed by AMR, as the District acknowledged a desire to work with a COTS application that was developed for water resources monitoring. AMR staff did attend onsite training in the WISKI application, which was provided by Kisters staff, but a full review of WISKI is beyond the scope of this report.

One trend which appeared numerous times during WISKI training (with access to live and historical data from the ACI database) was that the data from the PTs, was difficult to interpret in real terms. There was inconsistency in elevation data, sometimes jumping as if an elevation shift had been applied. While this could be due to calibration procedures, it was not clear, as the raw data was not stored, the database only contained values which had already been processed by unknown algorithms. This elevation issue was further complicated by different published elevation sources for key reservoir elevations which do not concur with each other (Table 2). The elevation data in the gauge database also does not correlate with the published elevations, and may also have inconsistencies with database ID to dam Site ID correlations. Additionally, the staff gauge markings at each of the sites does not appear to correlate with the gauge data. The bottom line from this spot review of data is that it is impossible to have a high degree of confidence in the gauge elevations with the current calibration and storage approach.

It was also notable that time series graphs of data from multiple PTs showed daily fluctuations which may be attributable to barometric pressure, potentially indicating problems with pinching or clogging of the associated PT vent tubes.

Read-only access to the ACI data is provided through a web interface, and a public website is hosted through Hivelocity Hosting out of Tampa, FL ($135 annually). The District does not appear to have direct access to the administrative functions on the ACI server. Kisters staff established a connection to the ACI data stream, and are maintaining an independent SQL database of FMS data.

Table 2 – FMS Sites Elevation Data (alternate sources)

		Data from Dams & Maps info webpages				*Data from FMS webpages*			
	FMS Site	**Primary (MSL)**	**Emergency (MSL)**	**Crest (MSL)**	**Crest - Primary (ft)**	**Primary (MSL)**	**Emergency (MSL)**	**Crest (MSL)**	**Crest - Primary (ft)**
Dam 1	Y	1012.5	1025.9	1030.8	18.3	1011.45	1026.18	1034.5	23.1
Dam 2	Y	947.2	962.0	967.0	19.8	948.3	962.84	971.33	23.0
Dam 3	Y	876.7	901.0	906.5	29.8	876.81	901.2	912.7	35.9
Dam 4	Y	838.3	858.9	863.9	25.6	838.3	859.	868.8	30.5
Dam 5	Y	886.1	902.9	907.5	21.4	886.61	903.33	910.92	24.3
Dam 6	Y	889.0	907.2	914.2	25.2	888.5	907.24	918.	29.5
Dam 7	Y	804.6	828.2	834.8	30.2	805.	829.	835.97	31.0
Dam 8	Y	826.4	846.8	881.8	55.4	825.5	847.09	852.62	27.1
Dam 9	Y	775.0	795.0	807.0	32.0	770.	785.4	792.5	22.5
Dam 10A	n	815.0	834.7	841.1	26.1				
Dam 10B	n	801.1	817.2	823.4	22.3				
Dam 11	Y	725.2	737.1	743.6	18.4	722.1	736.83	748.6	26.5
Dam 12	Y	768.0	782.3	787.3	19.3	767.83	782.27	789.5	21.7
Dam 13A	Y	829.4	841.8	846.0	16.6	829.4	841.8	850.3	20.9
Dam 14	Y	714.1	723.0	727.6	13.5	714.26	723.31	730.8	16.5
Dam 15	Y	699.0	709.2	713.5	14.5	698.94	709.	714.4	15.5
Dam 16	Y	719.0	729.5	734.7	15.7	714.29	729.57	739.5	25.2
Dam 17	Y	670.9	680.6	684.5	13.6	670.79	680.63	687.1	16.3
Dam 18	Y	659.5	671.2	676.7	17.2	659.24	670.81	678.94	19.7
Dam 19	Y	660.2	675.7	680.8	20.6	660.65	676.12	685.11	24.5
Dam 20	Y	649.0	660.2	664.7	15.7	649.3	661.22	667.9	18.6
Dam 21	Y	618.8	630.0	634.4	15.6	618.68	630.1	639.75	21.1
Dam 22	Y	600.0	609.7	613.8	13.8	599.9	609.47	615.6	15.7

It should be noted that there may be additional elevation values to those in Table 2, but which do not agree with either sets of the posted values, or they may be the same elevations, but referenced to different vertical datums (unknown at this time).

Operations Assessment

The District has 2 full-time staff (General Manager & Administrative Assistant), with only one (the GM) being trained in emergency operations. During extreme events, the GM can call in additional support as needed (Administrative Assistant, members of the Board of Directors), but they do not have the same level of training as the GM. There is no written comprehensive Emergency Action Plan (EAP) for flood response, although there are EAPs specifically written for the high hazard dams. According to interviews with the GM, the flood monitoring and response process is generally as follows.

The GM monitors weather National Weather Service (NWS) forecasts & radar and data from the FMS when attempting to estimate the risk of spillway engagements and potential overtopping, which could impact the survivability for each of the dams. This monitoring and forecasting effort is currently focused upon dam safety, as a core function of the District. There is however a potential need for additional discharge data (current and forecast) from the dams and points downstream, for use by property owners and communities downstream of the dams. The GM currently coordinates with the Office of Emergency Management for Williamson County (WilCo OEM) during flood operations.

Flood Risk Assessment

Understanding the flood hazard risks (probability of occurrence, impact severity, location and timing relative to flood generating events) is the most important factor in designing and operating an effective flood warning system. A cursory assessment of flood risk was performed by AMR, based upon FEMA flood hazard mapping and a GIS shapefile of addresses in floodplain, as published by Williamson County. Address counts both in the upstream flood pool and downstream to the District boundary can be found in Table 1, and Exhibit 2 (Appendix A) illustrates the locations of these flood hazard addresses. The address shapefile sometimes reflects actual structure locations, and sometimes reflects undeveloped properties, but can serve as a useful proxy for structure locations (with the caveat that there are likely less structures in the flood hazard areas than this cursory assessment might indicate). It is assumed that more accurate data may be available from other studies.

Maintenance Assessment

According to the small sample of dam sites that were visited and aerial imagery, all of the sites appear to be located within fenced areas, with locked gates for access. The locks are combination coded. All of the sites appear to have adequate clear weather vehicular access (lack on onsite visits to all sites prevents a comprehensive all-weather assessment, but aerial imagery indicates that some sites may have access blockage during flood events), although the roadway on top of the dams is narrow, and a single point of access may require drivers to drive forward to the sites, then back a considerable distance to exit (potentially problematic during low visibility conditions, as may be required during stormy weather).

Access to the precipitation gauges, dataloggers, radios, solar panels, batteries is good, but access to the PTs and float switches will require a bit of effort from maintenance staff. The bird deterrent wires should help reduce fouling of the tipping buckets, although it is unknown whether measures have been taken to deter spiders from building webs in the funnel or in the tipping bucket mechanism. Sediment buildup can cause measurement inaccuracies, and appears difficult to keep cleared, due to the design of the PT installations inside of the stage gauge riser pipes. Also, the access issues mentioned earlier with the float switch could make their inspection and maintenance difficult.

Without maintenance personnel on-staff, the District relies on contract maintenance support. While the details of the District's current maintenance agreement with HSE were not reviewed by AMR, scheduled maintenance should be performed at least quarterly, with data review to identify potential ad-hoc maintenance issues on a monthly schedule.

Financial Assessment

The District's total implementation cost for the FMS is estimated at $2.34 MM ($2.12 MM capital + estimated 10% design fee), which correlates to approximately $111 K per field gauging site. Annual maintenance expenses have been in the $10-25 K range for the past couple of years, plus approximately $5 K in annual expenses for DSL and web hosting.

The current 2013 budget includes $25 K for FMS maintenance and $ 5.4 K for DSL & web hosting. There are budget amendments pending that could increase FMS maintenance to $35 K, and $180 K for FMS improvements (incl. design). The FMS budget has been funded entirely from ad valorem taxes to date, although any potential grant funding for capital projects would likely be welcomed.

Partnerships Assessment

There are three operators of large hydro-meteorological warning networks immediately adjacent to the District; the United States Geological Survey (USGS), the Lower Colorado River Authority (LCRA), and the City of Austin (COA). AMR contacted all three to assess the potential of these agencies extending their services to include maintaining the District's 21 sites. The manager of the LCRA HydroMet system does not anticipate that such an agreement is likely, at least in the near future. The manager of the COA FEWS was not aware of an interest in such agreements, but followed that a discussion at the Department Director or Assistant City Manager might prove more fruitful. The USGS however, did voice interest in discussing such a partnership further. While the USGS is quite comfortable with providing turn-key services to local agencies and community partners, the local manager was unsure if they would have an offering that would utilize the District's existing infrastructure.

AMR also contacted the CAPCOG Homeland Security Director about the possibility of the District sharing their FMS data to regional agencies and communities via the COG's implementation of WebEOC, and the response was positive. The WilCo OEM currently uses WebEOC, and had recommended that the District consider participating as well. Communication was attempted with the City of Round Rock (CORR) concerning potential partnership, but have not made successful contact to date. Of all the adjacent communities, Round Rock stands the most to gain from a partnership with the District, as they have the most flood hazard properties downstream of District dams. The City of Hutto also has some flood hazard properties downstream of District dams, while the Cities of Cedar Park and Leander have numerous flood hazard properties in the watershed / District, but most of them are in reservoir flood pools or further upstream of the District's reservoirs.

The University of Texas Center for Research in Water Resources (UTCRWR), in partnership is Kisters and ESRI, has also begun to collect data from regional data providers, as another source of data centralization and sharing (Central Texas Hub), but it should be noted that this is a research and development system, and should not be relied upon as a primary means of coordination.

Recommendations

While the assessment of FMS hardware and software was abbreviated from the contract scope (as agreed by the District and AMR), there was sufficient information to reach conclusions on the capabilities of the current system, and to make reasonable recommendations on how to make best use of the current investment and future enhancements. A listing of the recommendations is shown in Table 3, but an overview is as follows.

Field Hardware: The field hardware was very ruggedly designed and installed, but not always in a manner that is conducive to accurate data measurement or maintenance. Of greatest concern is the implementation of water level sensors (PTs and Float Switches). PTs are maintenance intensive, especially in this design where sediment accumulation can be a concern; and open floats are subject to debris entanglement. Many operators of similar flood monitoring systems utilize Bubblers, which allows all of the sensitive equipment to be located in the protective enclosure with the datalogger, and a plastic hose extends to the point of measurement, where the bubbling process is somewhat self-clearing of sediment. Some other level measurement alternatives include RADAR (accurate, high cost, equipment must be placed above highest possible water level), shaft encoders, accurate, low cost but requires high cost stilling well), ultrasonic (temperature sensitive, must be installed above highest possible water level), and smaller, easier to maintain modular float switches. It is recommended that a best use of the District's investment into PTs would be to only use a single PT at each of the sites (in the lower position), maintain regularly to clear sediment accumulation and avoid moisture in the vent tubes, and retain the extra PTs for spares. Once all spares have been placed in service, subsequent replacements should utilize bubblers. At such time as the PTs are replaced with bubblers, it could also be advantageous to relocate the dataloggers to be positioned more closely to the Principal Spillway, where deeper water measurements can be obtained, and discharge measurements could be added at the outlet / in-stream (if desired) from the same datalogger, although communication paths would need to be tested at the revised locations during the design phase.

The precipitation tipping buckets appear to follow typical flood monitoring standards, and should function well, when typical maintenance practices are followed (remove debris and webs from funnels and tipping buckets, leveling and calibration). There are no significant recommendations for the precipitation gauging at this time.

The sites' power equipment appears sufficient, but it would be advisable to have power demands (watts when polling sensors, communicating with the base, and idle), solar panel power production (watts), and battery storage capacities (watt-hours) measured at each of the sites. This can be performed during the next phase of FMS design, or by maintenance personnel.

Base Station Hardware: The communications and application hardware located at the Base Station was not fully reviewed, as information on the ACI hardware did not provide sufficient detail, and the WISKI hardware appeared to be specified by Kisters (and was assumed adequate). However, no redundancy was observed in the following areas, leaving each as a potential single point of failure for the FMS during a flood emergency:

1. Communication path (900 MHz radio only)
2. Communications application (ACI on single server)(WISKI does provide a redundant database for ACI, but is dependent upon ACI to collect the data)
3. External communications to the District / Internet (DSL only)

It is recommended that each of these systems receive redundant capabilities, with items 1 and 2 requiring long term considerations in the FMS design phase, but item 3 could be addressed in the very near term with cable Internet access (which would also improve system access speeds).

Base Station Software: The ACI software was not directly observable during the assessment, and it is understood that a COTS application for flood monitoring applications is desired by the District. The WISKI application was not fully reviewed, but a cursory review during on-site training was favorable, and it is a widely used COTS water resources application, with additional capabilities in the flood monitoring arena. Software applications to be considered during the FMS design phase should be evaluated on the following capabilities:

1. Control of communications with the field sites (interrogation (scheduled & ad-hoc) by base station and/or event transmission from field sites), with the ability to manage multiple communications paths (simultaneous or redundant stand-by)
2. Data storage, archival and retrieval using open database standards
3. Ability to execute hydrologic forecast models
4. Ability to generate areal precipitation based upon NWS RADAR, with adjustments for gauge values (District and adjacent FMS operators)
5. Alarm threshold monitoring by data values (above limit, below limit, etc) and custom formulas (rate of rise, basin precipitation average, forecast model results, etc)
6. Real-time alarm dissemination to external users (web, SMS, e-mail, phone, etc)
7. System redundancy, with hot fail-over (applications and databases)
8. User interfaces for FMS operators / administrators, external agencies, and the general public

It is understood that Kisters offers application modules that can meet some of these needs, but it is recommended that several additional software packages be reviewed for their ability to meet the functional and financial needs of the District. Software review should include the following vendors / software packages, at a minimum:

- Kisters (SODA, KiAlarm, WISKI-WEB, KiWIS-Web, WIKSI-TSM, WISKI ArcView)
- Vieux (Vflo, Pre-Vieux)
- OneRain (Contrail Base Station, Contrail Web Hosted)

Some of these vendors offer web hosting not only for the data, but also for the applications themselves, which could reduce system maintenance concerns for the District.

Operations and Maintenance: The District's operation of the FMS is constrained by its staffing level, but the level of staffing appears appropriate to serve its mission. During flood emergencies, it is likely that staff will be severely tasked, and there does not appear to be a trained backup available, should the GM not be available during an event. If a backup is needed, there also does not appear to be a written Flood Emergency Action Plan, which could help guide personnel through the required activities. The District does have good relationships and communications with area agencies and communities, which could provide assistance during an emergency. Maintenance of the FMS is contracted to several firms, which can provide for accuracy and reliability, but some changes should be warranted. As such, the following changes are recommended:

1. Prepare a written Flood EAP, which should be a living document
2. Provide basic training on the FMS to all District staff and Directors
3. Publish FMS data for rapid, reliable access by adjacent communities and partner agencies (WebEOC and the Central Texas Hub are 2 options which offer such capabilities)
4. Discuss the needs of adjacent communities and partner agencies, to determine if additional functionality for the FMS (downstream monitoring, downstream forecasting, etc) would provide them with useful benefits, and if they would be willing to partner in such an expansion to the FMS

Table 3 – Recommendations for FMS Enhancement

Item	Current Functionality	Recommendation	Criticality of Current Need	Cost Estimate (materials & labor)	Timing	Comments
Field Hardware						
Pressure Transducers	Poor	Improve maintenance, ultimately replace with bubblers	High	$5,000 / site	Replace as PTs are damaged and no spares remain	To extend the financial life of the current investment in PTs, the water level can be measured with single PTs at each site, and pull the extras for spares, also refer to Maintenance recommendations to improve short-term functionality
General Site Access	Fair	Provide reflective markers to guide vehicles during backing maneuvers	Medium	Low?	As soon as possible	Improved safety of maintenance personnel
Elevations	Poor	Perform field surveys of key dam elevations and water level monitoring sensors	Medium	$2,000 / site	As soon as possible	All elevations should be referenced to NAVD 88, to correlate with FEMA flood hazard mapping, staff gauges should be referenced to primary spillway elevations, and gauge data should calibrated to correlate with staff gauge readings
Float Switches	Unknown	Replace with smaller, modular float switches	Medium	$1,000 / site	Replace as existing Float Switches are damaged and no spares remain	Also refer to Maintenance recommendations to improve short-term functionality
Radios & Antennas	Good	Retain and maintain (see note on confirmation of power in Solar Panels), investigate redundant communications	Medium	Design dependent	Review redundant communications options during FMS design phase	Current licensing good until mid-2019, no regulatory impacts proposed in the licensed bands, radio manufacturer (MDS) should be able to support radios, redundant communications should be investigated during design phase
Solar Panels	Good	Confirm power demands (dataloggers & radios) and capabilities (solar panels & batteries)	Low	Low	During design phase, or as part of maintenance cycle	Remain on the lookout for enhancements for replacements as current Solar Panels are damaged and no spares remain, also depending on future dataloggers, power requirements could be significantly reduced, allowing smaller Solar Panels
General Site Configuration	Fair	Relocate dataloggers and water level sensors (PTs / floats / bubblers / etc) to allow water level measurement in deeper water, possibly at primary spillway risers	Low	High construction cost	Long range, when other conditions warrant relocation or replacement of standpipes	By placing a bubbler orifice in deeper portions of the pool, more advance warning can be provided on level rise during low pool conditions, bubblers tend to be lower maintenance (self clearing of sediment), and the primary spillway risers offer rigid structures for mounting
Mounting Pole	Good	Replace with smaller poles	Low	$1,000 / site	Replace as standpipes become damaged and no spares remain	Current aluminum standpipe works well, but lower cost options can work just as well
Tipping Buckets	Good	Retain and maintain	n/a	n/a	n/a	Remain on the lookout for enhancements for replacements as current Tipping Buckets are damaged and no spares remain
Dataloggers	Good	Retain and maintain (see note on confirmation of power in Solar Panels)	n/a	n/a	n/a	Remain on the lookout for enhancements for replacements as current PLCs are damaged and no spares remain, also there are dataloggers that currently allow multiple communication paths, for greater redundancy, and reduced power demands

Item	Current Functionality	Recommendation	Criticality of Current Need	Cost Estimate (materials & labor)	Timing	Comments
Grounding	Good	Retain	n/a	n/a	n/a	Electrical damage often occurs due to impressed current from nearby lightning strikes (not direct to equipment), with long PT cable runs a common culprit, replacing PTs with bubblers can significantly reduce grounding issues
Base Station Hardware						
External Communications	Fair	Supplement DSL with redundant communications	High	$1,000 / year	As soon as possible	Redundant communications between Base Station and the Internet is critical, a relatively low cost, 2nd communications path should utilize different media (cable?) and a different provider than the current DSL
Radio & Antenna(s)	Good	Retain and maintain, investigate redundant site communications options	Medium	Design dependent	Review redundant communications options during FMS design phase	Second cable visible but disconnected in communications shelter, unknown if redundant antenna available on the tower; redundant communications should be investigated to remove potential single point of failure
General Site Access	Good	Replace keyed locks with combination locks, combination included in Flood EAP	Low	Low	As soon as possible	Triple layers of controlled access (Police check-in required, combination locked gate, and key locked shelter) can delay access, especially if key mis-placed or combination forgotten
Computers	Good	Retain and maintain	n/a	n/a	n/a	See Software recommendation concerning hardware redundancy
Power	Good	Retain and maintain	n/a	n/a	n/a	
Software						
ACI Custom Applications	Poor	Replace with COTS flood monitoring application	High	Coupled with replacement software (below)	As soon as replacement application(s) are online (below)	Custom applications are not well documented, difficult to manage, and future support is uncertain, computing hardware should be considered for system redundancy, dependent upon Kisters software capabilities in this area
Kisters WISKI	Good	Investigate capabilities to replace ACI functionality	High	Design dependent	Determine appropriate software approach during FMS design phase, and implement as soon as possible	Kisters software is COTS water resources monitoring ready, with support likely available well into the future, existing local expertise can be shared from COA and UTCRWR, redundant system should be considered; other software options should also be considered during the design phase, with data and flood warning applications potentially hosted off-site, review whether web applications use vendor web hosting, or District web-hosting
NWS RADAR	Good	Consider adding commercial service with gauge adjusted aerial precipitation forecasts and estimates	Medium	Design dependent	Investigate RADAR applications during FMS design phase, and implement as soon as possible	Some service providers (e.g. Vieux) can also provide real-time hydrologic modeling based upon areal precipitation forecasts and current precipitation estimates

Item	Current Functionality	Recommendation	Criticality of Current Need	Cost Estimate (materials & labor)	Timing	Comments
Operations						
Flood EAP	Poor	Prepare written plan for operations before, during and after flood events	High	Low	As soon as possible	A basic document should be prepared by staff, which identifies that process that is currently followed, as a living document which is intended to reflect changing conditions in the watershed / District / adjacent communities, this document can allow greater consistency and portability with staff; all District staff and Directors should receive a basic level of training in the operation of the FMS (as potential backups)
Partnerships	Fair	Maintain regular communications with key agencies and adjacent communities	High	Low	Ongoing	Communications with CAPCOG (data sharing) should begin immediately, USGS site implementation and maintenance costs likely prohibitive, but should be discussed
FMS Design	n/a	Proceed with FMS Design Phase	High	Scope dependent	As soon as possible	A well designed system (by professionals with experience in flood warning system design) should easily reduce the future capital and O&M costs to more than cover the initial design cost
Dam Safety or Basin Flood Warning?	Good	Retain FMS for dam safety monitoring, consider expansion for flood warning enhancement to other communities	Low	Design dependent	Investigate cost options during FMS design phase	Expansion into a broader watershed flood warning system will require additional gauging and new sites at substantial cost, communities which will benefit from such should be encouraged to underwrite much of the expense
Maintenance						
Schedule	Unknown	Ensure regularly scheduled and unscheduled maintenance be addressed in maintenance contract	High	Low	As soon as possible, if not already implemented	Scheduled site maintenance should occur at least quarterly, with ad-hoc maintenance based upon District request and monthly data review
Pressure Transducers	Poor	Ensure PTs are well maintained until transition to bubblers	High	Low	As soon as possible	Vent tubes should be kept clear and unkinked, with dry desiccant packs at vent tube caps, sediment should be kept clear from PT sensors
Float Switches	Unknown	Ensure that Float Switches are well maintained until transition to modular units	Medium	Low	As soon as possible	Float Switch vaults should be kept clear of debris which could inhibit float movement, until transition to modular units, as sites are secured, vandal proof fasteners should be replaced with standard fasteners
Records	Poor	Keep records of all site maintenance	Low	Low	Regular maintenance	Records should include checklist of maintenance items with observed values, maintenance tasks and general notes
Precipitation Tipping Buckets	Unknown	Maintain tipping buckets and funnels	n/a	n/a	Regular maintenance	Keep funnels and tipping buckets clear of debris and webs, tipping buckets kept level and calibrated, overhead obstructions (i.e. vegetation, structures, wires, etc) should be kept away

Item	Current Functionality	Recommendation	Criticality of Current Need	Cost Estimate (materials & labor)	Timing	Comments
General Site Maintenance	Good	Maintain site access	n/a	n/a	Regular maintenance	Keep roadway clear of debris and excessive vegetation, provide clear access to water level sensors
Base Station	Unknown	Maintain site security and function	n/a	n/a	Regular maintenance	Software can be maintained remotely, but on-site access should also be available, shelter should be kept organized and clear of pests, A/C thermostat controlled
Financial						
Partnerships	Good	Maintain regular communications with key agencies and adjacent communities	Low	Low	Ongoing	Limited financial partnerships likely, unless expansion provided to basin flood warning system, which should require some degree of partner funding
Grants	Poor	Stay abreast of available grant programs from FEMA, DEM, TCEQ, TWDB	Low	Low	Ongoing	Many grants are tailored for flood reduction programs, but there are instances where flood warning capital equipment can be funded