Memorandum

To: Dr. Wilbert Odem, Dr. Paul Trotta, and Mr. Justin Ramsey

From: Timothy Mahon, Patrick Belsheim, and Ali Alrayyes

Date: 10/17/2013

Re: Routes Decision Matrix

Decision Matrix Methodology

The decision matrix for the OWDP Facility analyzes the four alternative force main routes as seen in Figure 1. The four force main routes were designed to utilize a 4 inch PVC Sch 40 pipe. The roughness or C coefficient of the Hazen-Williams equation of each pipe was assumed to be the same for the four alternatives. This assumption was based off the fact that all 4 force main routes use the same piping material. ADEQ R18-9-E301.4.01 requires the force main routes to be designed using a Manning's roughness coefficient of $n = 0.013$ and a minimum velocity of 2 ft/s; the ADEQ regulation also requires a minimum velocity of 3 ft/s and a maximum velocity of 10 ft/s when the final route is designed.

Criteria Description:

Cost

The cost criterion considers the price of construction, maintenance, operation, and the price of the length of pipe required to complete each of the alternative routes. The weighting given to this criterion was set at 4.00 out 5.00, because the final cost of the desired force main route will have a heavy impact on the economic feasibility of the project. A route which was considered expensive received a low score, while a route which was considered less expensive received a higher score.

Length of Pipe

The length of pipe criteria considers the overall length of pipe necessary to build each of the alternative force main routes. A longer route will require more piping material which will affect the overall cost of the force main route; so a shorter pipe is preferable to a longer one. A longer route may also increase the head losses in the system, which would increase the necessary pump size in order to pump the wastewater to the OWDP site. A weighting factor of 2.00 out of 5.00, was used on this criterion, because the length of pipe factors into the cost, head loss, and maintenance criteria. A route which required a long length of pipe received a low score, while a shorter route received a higher score.

Head Loss

The third design criterion is the head loss expected along each force main route. The team used basic hydraulic principles to approximate the expected head loss in each force main route. If a pipe has a higher velocity, the head loss will be increased due to run of pipe and pipe fitting losses. Properties which can have influence over the velocity values of the routes include: the route's grade and the diameter of the pipe. A longer pipe length will increase the run of pipe losses. The Hazen-Williams formula illustrates these principles once head loss is solved for.

$$Q = 0.432CD^{2.63}S^{0.54} \text{ (English Units)}$$

$$\rightarrow Q = 0.432CD^{2.63}\left(\frac{h_L}{L}\right)^{0.54}$$

$$\rightarrow Q^{1.85} = 0.432^{1.85}C^{1.85}D^{4.87}\frac{h_L}{L}$$

$$\rightarrow h_L = \frac{Q^{1.85}L}{0.212C^{1.85}D^{4.87}}$$

Where,

Q = flow (cfs) = vA (Velocity (ft/s) * Area (ft^2))

C = Smoothness constant of piping material (C = 148 assumed for 4 inch diameter PVC)

D = Diameter of pipe (ft)

S = Slope of hydraulic grade line (ft/ft) = $\frac{h_L}{L}$

h_L = Head Loss (ft)

L = Length of pipe (ft)

After the Hazen Williams equation is solved for head loss, it is visible that an increase in velocity and/or length will increase the head loss of the pipe. An increase in pipe diameter will reduce head losses and the velocity in the pipe. Lower head loss values were given a high score. If a route had an expected high head loss value, then the route was given a low score. The head loss criteria was given a weight of 2.00 out of 5.00 because the lift station design will be able to overcome any head loss elevations for any route.

Gravity / Pumped

The fourth design criterion is the route's ability to deliver the wastewater by gravity alone, or whether a pump will be required to deliver the wastewater to the OWDP facility. The wastewater can be gravity delivered to the OWDP site if the grade of the pipe stays over 1.00% and does not exceed 8%. These grades are based off of the ADEQ R18-9-E301.4.01 requirements to ensure that the minimum velocity of 3 ft/s and maximum velocity of 10 ft/s are met. The pipe must also meet minimum and maximum depth criteria, which influences the capabilities of the route to be gravity delivered. A route able to be gravity delivered will receive a higher score. A route requiring a pump will receive a lower score. The gravity or pump criteria was given a weight of 1.00 out of 5.00, because after evaluating all four routes, it became clear that all alternative routes will require a pump.

Constructability

The fifth criterion, constructability, includes the construction of a new lift station, excavation, and trenching of the force main to deliver residential wastewater from Family Housing, to the existing lift station of the OWDP facility. The construction of the lift station and force main are based on ADEQ R18-9-E301.4.01 requirements. A weighting factor of 3.00 out of 5.00, was used on this criterion because the cost and grade criteria were valued with higher weighting factors, however constructability still has strong influence over the chosen alternative.

Inconvenience / Disturbance

The sixth criterion evaluates the level of disturbance caused by the construction of the force main around the proposed routes. The criterion was added because the project requires excavation, which could potentially disturb the residents, because the potential force main routes cut through the parking lot or right through two housing units. A weighting factor of 2.00 out of 5.00, was used on this criterion, because the inconvenience caused by potential construction

would only be temporary. The scores given to the alternative force main routes, vary because each route has its own distinctive path. In addition, all the proposed routes will require a temporary shut off of the water supply, for the housing units, to connect the force main to the manhole junction.

Maintenance

The seventh criterion evaluates the level of scheduled maintenance required for the force main and the force main components, such as the valves and the lift station. The scores vary for the proposed routes as the length of the force main impacts the scheduled maintenance. A weighting factor of 2.00 out of 5.00, was used on this criterion because maintenance is a necessary routine, required for the force main's operation.

Grade

The eighth design criterion is the percent grade or slope of pipe for each route. The grade of pipe for each route affects the velocity in the pipe and therefore affects the head loss in each pipe. The head loss affects the pump size needed to pump the wastewater to the OWDP site, which in turn affects the overall cost of the project. The grade of the pipe has a high impact on the overall project. In order to convey the importance of the grade, the team gave the grade criteria a weight of 5.00 out of 5.00. A route which was able to meet grade criteria was given a high score. A route which either did not meet grade requirements or had poor grade design was given a low score.

Routes Description

Route 1

The values and scoring for Route 1 can be seen in Table 1.

For cost, Route 1 was given a score of 4. Route 1 is the longest route to the OWDP site. The combined cost of excavation, construction and length of pipe material are the highest out of the four routes.

For length of pipe, Route 1 was given a score of 1. Route 1 was found to be the longest route to the OWDP site and required the longest length of pipe.

For head loss of pipe, Route 1 was given a score of 5. This medium score is due to the velocities meeting ADEQ R18-9-E301.4.01 requirements. While the routes velocities were

acceptable, the overall length of the pipe would greatly increase the head losses. The length of the pipe reduced the final score for head loss of pipe.

For gravity/pumped, Route 1 was given a score of 2. This score was low because the route would require a pump and cannot be gravity delivered to the OWDP site.

For constructability, Route 1 was given a score of 4. The route requires the most amount of construction materials and earthwork to build. As the route is the longest and the force main goes around the ROTC training course. The route would require the construction of a lift station.

For inconvenience or disturbance, Route 1 was given a score of 10. The score was high because the route goes around the ROTC training course and away from the Family Housing Complex. This route reduces the inconvenience for the residents during the construction phase of the project.

For maintenance, Route 1 was given a score of 5. This score is based on the long length of the route which would make maintaining it troublesome. The long length would also increase the amount of scheduled maintenance.

For grade, Route 1 received a score of 10. Route 1 was found to be within the acceptable design criteria of 1.00% to 8.00% grade, set by R18-9-E301.4.01. The team initially designed Route 1 to be gravity delivered. The topography and ADEQ R18-9-E301.4.01 requirements would not allow it. After careful analysis, it was found it would not be possible to gravity deliver for Route 1. This was due to the fact that after meeting ADEQ R18-9-E301.4.01 requirements, the pipe would be over the maximum depth constraints. Route 1 was redesigned to be pump delivered and all grade requirements were met.

The final score for Route 1, as seen in Table 1, was found to be 122.

Route 2

The values and scoring of Route 2 can be seen in Table 1.

For cost, Route 2 was given a score of 8. Route 2 is the most direct route to the OWDP site. The amount of piping material needed for this route would be the lowest amongst the alternatives. The route would require the design and construction of a lift station, but it was found that all alternatives would require this. Since the length of pipe is the lowest for this route, the amount of earthwork required would be the lowest, as well.

For length of pipe, Route 2 was given a score of 7. Route 2 was found to be the most direct route to the OWDP site and required the lowest length of pipe.

For head loss of pipe, Route 2 was given a score of 4. This low score is due to the grades in Route 3 being too high. The grades in Route 2 did not meet the ADEQ R18-9-E301. 4.01 design requirements. The grades associated with Route 2 would increase the velocity, which would increase the run of pipe and fitting losses.

For gravity/pumped, Route 2 was given a score of 1. This score was low because the route would require a pump and cannot be gravity delivered to the OWDP site.

For constructability, Route 2 was given a score of 6. This score reflects the short length of the route. The route would require the least amount of construction materials and the least amount of earthwork to build. The route would require a lift station design, but it was found that all routes would require the wastewater to be pumped to the OWDP site.

For inconvenience or disturbance, Route 2 was given a score of 3. The score was low because the route goes directly through the parking lot of the Family Housing Complex. This would be a major inconvenience, because temporary parking would have to be set up for the residents during construction of the route.

For maintenance, Route 2 was given a score of 6. This score reflects the short length of the route which would make maintaining the route less cumbersome. The route would require a pump which would need to be maintained as well.

For grade, Route 3 received a score of 1. Route 2 greatly exceeded the maximum grade of 8.00%. Route 3's grade exceeds the design criteria of ADEQ R18-9-E301.4.01.

The final score for Route 2, as seen in Table 1, was found to be 94.

Route 3

The values and scoring of Route 3 can be seen in Table 1.

Route 3 received a score of 6 in the cost criteria, because the cost of excavating and trenching the pipe between two of south Family's Housing Complexes would be very cost prohibitive. The cost of a lift station was also considered in the scoring of this route. A 7 was given to route 3 in the length of pipe criteria, because route 3 requires the exact same length of pipe as route 2.

Route 3 received a score of 4 in the head loss criteria because the higher velocity associated with route 3 leads to a higher head loss value.

Route 3 received a score of 1 in the gravity/pump criteria because it is not possible to have the residential wastewater flow to the OWDP facility by gravity alone. If the wastewater was allowed to flow through route 3 by gravity, the wastewater would settle and clog the force main, damaging the pipe and violating ADEQ's regulations concerning force mains. Route 3 received a score of 5 in the constructability criteria because a lift station is required, and excavating the area in-between the two Housing units will require blue staking to avoid existing utilities.

Route 3 received a score of 2 in the inconvenience/disturbance criteria because excavating and placing route 3's force main will be a major inconvenience to the residents in the two Housing units, which route 3 passes through. The residents will not only be disturbed by the noise of the construction, but their water may need to be turned off to accommodate the construction of Route 3.

Route 3 received a score of 7 in maintenance because the short length of pipe will make the cleaning and scheduled maintenance of the pipe relatively easy. Route 3 received a 2 in the grade criteria because the profile does meet the grade requirements of ADEQ R18-9-E301.4.01.

All of these scores combined, led to Route 3's overall score of 90, as seen in Table 1.

Route 4

The values and scoring of Route 4 can be seen in Table 1.

For cost, Route 4 was given a score of 5. The cost of this route would be intermediate when compared to the costs of Routes 1 and 2. Route 4 would be shorter than Route 1 but longer than Routes 2 and 3. The cost reflects the price to purchase the piping materials, excavate a trench, and install a lift station. The route has well designed grades and a reasonable length of pipe, which would reduce the head losses in the route, and decrease the pump size.

For length of pipe, Route 4 received a score of 5. This score is due to the route being at a median length when compared to the other three alternative routes. The length of the route affects the piping material, size of septic tank, and pump size needed.

For head loss, Route 4 was given a score of 8. Route 4 will have the lowest head losses of the four alternative route designs. This is due to the route having well designed grades in order to

reduce the maximum velocities through the pipes. As seen earlier in the Hazen-Williams equation, an increase in velocity would increase the head losses.

For gravity or pump delivered, Route 4 received a score of 2. This is due to the route being designed to reduce head losses, which would reduce the pump size needed for the system. All routes were found to need a pump.

For constructability, Route 4 was given a score of 6. This score is due to the route meeting minimum and maximum grade requirements set by ADEQ R18-9-E301.4.01. The route meets these requirements by staying below the minimum depth of 3 ft and staying above the maximum depth of 10 ft, required by ADEQ. The route is a median length which would require less cut and fill than Route 1. Route 4 would require the construction of a hydraulic lift station in order to overcome the terrain along the force main's route to the OWDP site.

For disturbance, Route 4 was given a score of 8. The route would go around the parking lot located north of the Family Housing Complex. The route would be far enough away from the Housing structures as to not create a nuisance for the residences.

For maintenance, Route 4 was given a score of 6. The route would be relatively easy to maintain due to the route location and the profile depths. The shorter length of the pipe will make the head losses smaller and the frequency of maintenance low. The route will require a smaller pump relative to other routes which would increase the efficiency of the lift station.

For grade, Route 4 was given a score of 9. The route would utilize the slopes of the hill between the Family Housing Complex and the OWDP site, to deliver the wastewater to the valve distribution vault. The grades of Route 4 meet the maximum and minimum grade requirements, which are related to the maximum and minimum velocities set by ADEQ R18-9-E301.4.01.

The final score for Route 4, as seen in Table 1, was found to be 139.

Chosen Route

The route chosen was the route which received the highest total score. The final scores for all four routes can be seen in Table 1. Route 4 is the desired alternative route, because the route received a total score of 139, while routes 1-3 received scores of 122, 94 and 90 respectively. Route 4 was designed to be gravity flow but the team found the route will need a pump to deliver the wastewater to the OWDP site. Route 4 meets all the ADEQ R18-9-E301.4.01 requirements

for minimum depth, minimum and maximum velocities. Route 4's path in between the parking lot and the ROTC training course minimizes the disturbance to the residents of the South Family Housing Complex, because only a small part of the parking lot will need to be closed for construction. Route 4 will have the lowest amount of head losses, compared to the other routes, so smaller pumps can be used in the lift station design. The length of pipe for Route 4 is longer than routes 2 and 3, but the length of pipe for route 4 is considerably shorter than the length of pipe required for route 1.

Table 1 Alternative Design Decision Matrix for 4 Routes

No.	Decision Matrix Criteria	Weight	Route 1	Route 2	Route 3	Route 4
			Score	Score	Score	Score
1	Cost	4.00	4	8	6	5
2	Length of Pipe	2.00	1	7	7	5
3	Head Loss	2.00	5	3	4	8
4	Gravity / Pumped	1.00	2	1	1	2
5	Constructability	3.00	4	6	5	6
6	Inconvenience / Disturbance	2.00	10	3	2	8
7	Maintenance	2.00	5	6	7	6
8	Grade	5.00	10	1	2	9
Scoring 1 = Low (Bad) 5 = Medium 10 = High (Good)		**Total Score**	**122**	**94**	**90**	**139**

Appendix

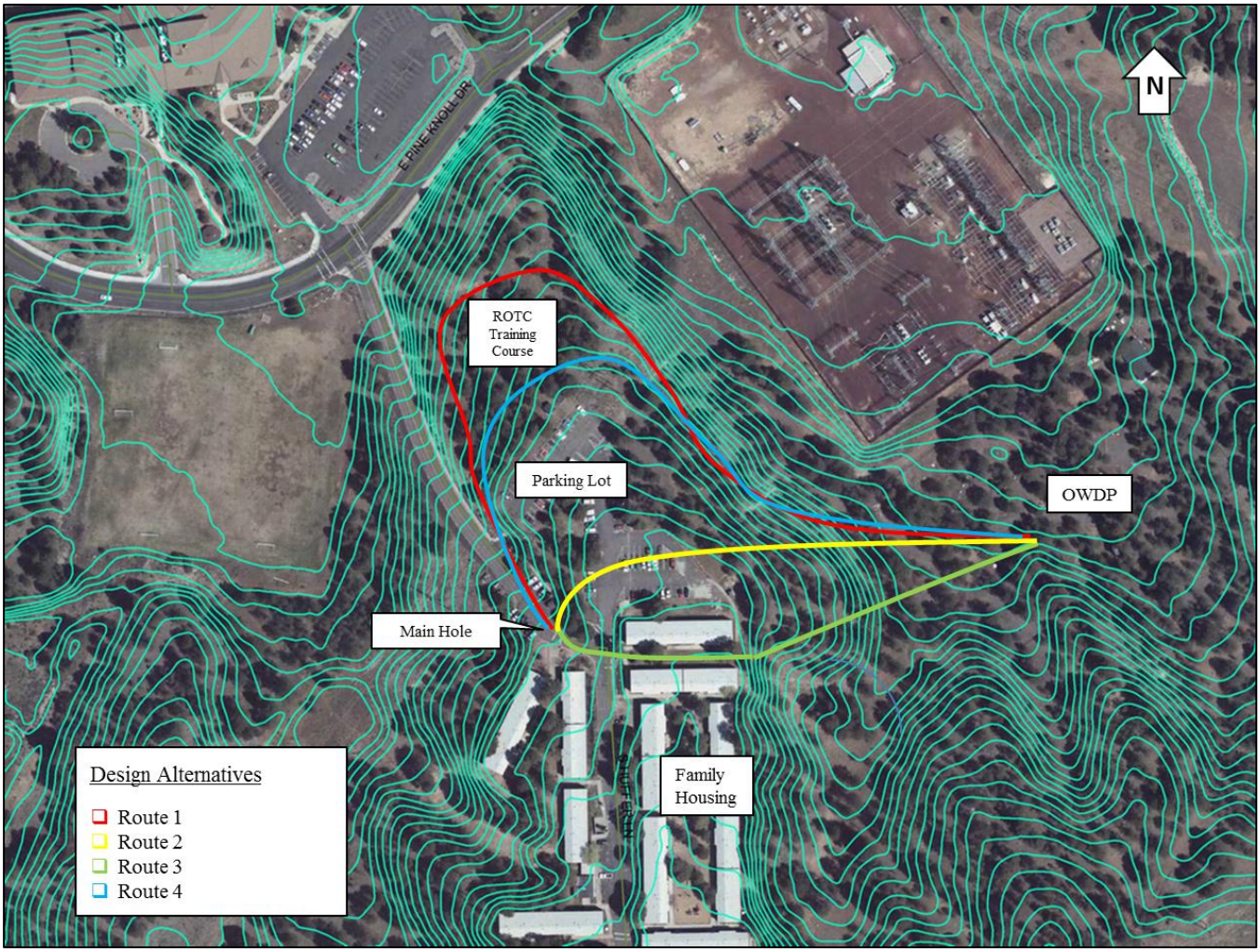

Figure 1 Alternative Design for 4 Routes