MAGNET4WATER ConduitNET SAMPLE PROJECT 2

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The following student exercise considers a hypothetical water distribution system, although the project on which it is based is real. The design aspects specified in this project are for educational purposes only and do necessarily reflect real-world conditions.

This is a *Request for Proposals* (RFPs) in support of Water Distribution and Sustainable Irrigation Project in a rapidly developing part of the world facing significant water issues. The Project involves a riverbank filtration system and a large-scale transmission pipeline to move water from a freshwater "corridor" along the Indus River to a desert area to be converted into farmland. The overall goal is to transfer water at minimum cost. The Project Team will calculate total irrigation water demand, design the large-scale water transmission system, and estimate construction and annual operational costs.

MOTIVATION

Over the past several decades, Pakistan has transformed from a county of under 50 million people to well over 225 million today. This population growth has significantly increased water demand, but water availability varies significantly across the country (e.g., the north is "very wet", while the south and eastern regions are generally dry deserts).

Traditionally, canals have been used to move water to areas in need, but this has proven to be grossly inefficient - as much as 80% of the water is lost during delivery because of evaporation and leakage out of the unsealed canal channels! The canals and other human activities / contamination have also caused water quality to drop below acceptable levels, exacerbating the water availability problem. This is particularly concerning at a time when the country needs to increase crop yields and improve its water, food, and economic security.

An innovative Sustainable Irrigation System Plan has been proposed to solve the water crisis. The Plan relies on riverine freshwater reservoirs that will be "redistributed" to dry rural areas through a large-scale water distribution (pipe network) system - a so-called "loss-less delivery" system.

The massive fresh groundwater reserves underlying (and connected to) the major rivers will be pumped via extraction wells that are linked to the larger water distribution system that moves water to rural areas (see Figure 1). Most of the pumped water will ultimately come from the rivers – a so-called "sustainable abstraction" (because the aquifer is not losing water over time!) - and is filtered by the riverbed and aquifer sediments, thereby improving the water quality.

Booster pumps will be added to the main distribution pipelines connecting the well fields to the desert areas (i.e., proposed irrigation fields). More detailed distribution networks of pipes, storage tanks, values, etc. will be needed in each local area to satisfy water supply and demand. To "make every drop count", precision farming techniques will be utilized at field-scale that automatically adjust to crop water requirements (Fig. 1).

The Sustainable Irrigation System Plan is a vision for the entire country, but the first step is to demonstrate its feasibility for a specific "source site" (freshwater reservoir area) and "use site" (network of irrigation fields). That is precisely the prerogative of this RFP.

Showcase Site - The proof-of-concept project will have its source site is at the confluence of the Indus River and its major tributaries in the central part if Pakistan. The use site is a large region of the desert to be converted to farm land, about 65km southeast of the source site (see Figure 2).

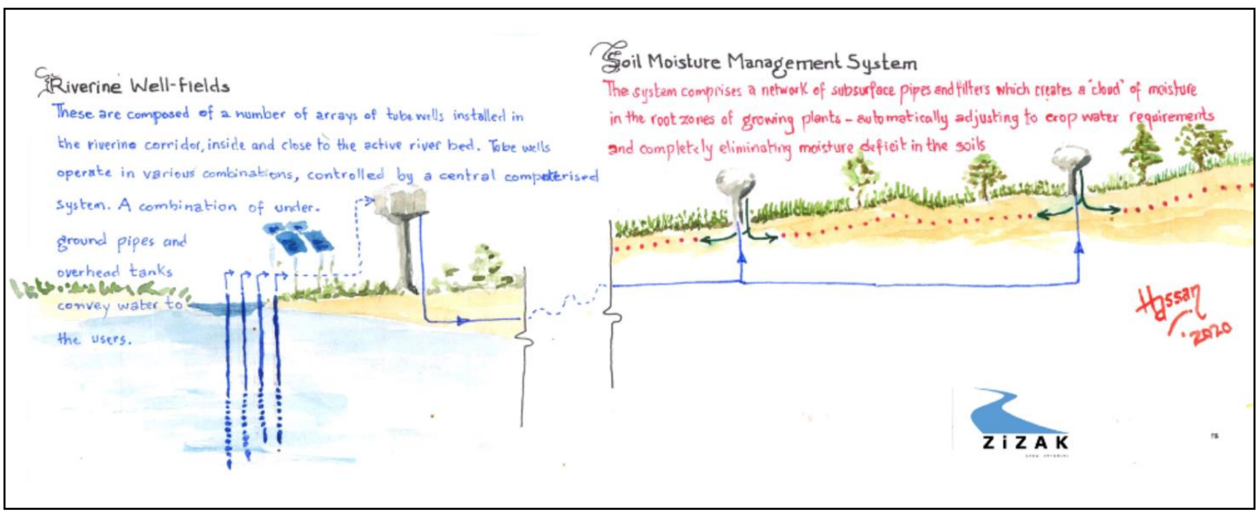

Figure 1: Conceptual diagram of the proposed riverbank filtration and water distribution process. Created by Dr. Hassan Abbas, ZiZAK.

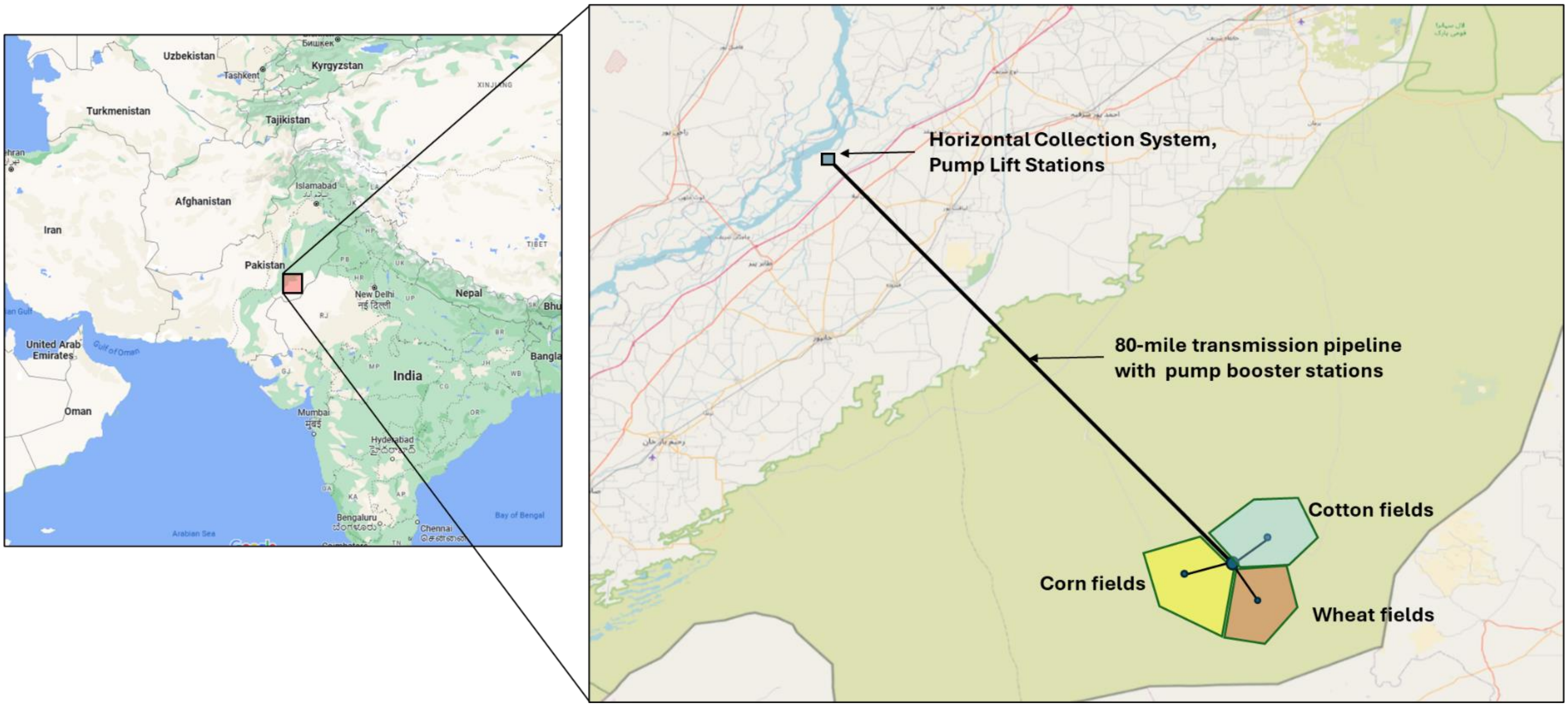

Figure 2: Locations of the source area (wellfield) and use area (farmland) of the proposed “Showcase Site” in east-central Pakistan.

OBJECTIVE

The Project Team will be expected to successfully complete the following objectives to enable transmitting water from the well field to the desert at a minimum cost:

1. Compute total water demand (based on crop water demand, irrigatable land area)
2. Evaluate the feasibility (and finalize the design) of an innovative “horizontal collector system” and off-river lift pump station
3. Design the transmission pipeline (diameter, material, and elevation/slopes)
4. Design the “booster” pump stations, if needed (locations, booster/pump curve, number of stations needed)
5. Calculate total estimated energy costs
6. Calculate total estimated construction costs
7. Compare costs for low-speed operation and high-speed operation

Further instructions and details regarding each major step are provided in the sections below.

DELIVERABLE

Please summarize your findings in a clear, well-organized Memo. Please limit the Memo to two page (single-space) and submit detailed supporting documentation and technical details as an Attachment or Appendix.

Your Appendix should include detailed model information to support the conclusions and recommendations made in your Memo, in the form of a PowerPoint (PPT) presentation. In particular, your Appendix should include the following information:Project Motivation and Objective (rephrase/summarize)

1. Water Demand Calculation. Present and calculations related to total water demand (design flow).
2. Collector System and Lift Pump Station Design. Describe the pump performance and energy costs associated with lifting the groundwater from the horizontal collection wells to the transmission pipeline at the surface. Describe sensitivity of energy cost to design aspects (e.g.,low-speed vs. high-speed, pump efficiency).
3. Transmission Pipeline Design. Present and discuss the design aspects (including costs) of the transmission pipeline and booster pump stations. Note the design velocities and design diameters utilized and associated energy cost considerations. Describe the pressure dynamics in the pipeline and the booster pump station design (performance specifications, number of boosters, etc.). Use graphical representations (e.g., Profile Plots, 3D Plot) to aid in your presentation of your final design performance. Utilize sensitivity analysis (hypothetical changes to design parameters) to illustrate variability related to costs/economics of design (e.g., transmission pipe velocity / diameter, pipe material, wellfield pump station design (design flow and head), booster pump station design (design flow and head).
4. Conclusions and Recommendation. Reiterate the final “take-home” messages and propose future work to improve the overall water transmission system.

Your Appendix needs to be professional and comprehensive. There is no length limit on the Appendix. But imagine you will deliver the PPT presentation to your client in 25 minutes.

OVERVIEW OF ANALYSIS

NOTE: Please read the following sections completely before starting! The design process is highly integrated – the various calculations are "coupled" or often require sharing of information / parameter values, etc. It is useful to have a high-level understanding of the entire process before working through details.

The MAGNET4WATER ConduitNET[1] - Pipe and Conduit System Analysis Network Platform - web application will be used to model and analyze the flow dynamics (velocity, head, pressure) across the proposed water collection ad transmission system. See "ConduitNET Quick Tutorial" if you are a beginner:

1. Navigate to MAGNET4WATER ConduitNET: https://www.magnet4water.org/conduitnet/
2. In the header Menu bar, go to: TUTORIAL > Quick Tutorial

The Quick Tutorial explains step-by-step how to add network objects, assign attributes, run the model, and visualize / analyze the results.

Key Design Constraints: Velocity and Pressure

The pipes available for the project have a permissible design velocity range of 0.5 m/s - 3 m/s (1.6 ft/s – 9.8 ft/s).

The pressure in the pipeline (nodes, links) must always be positive but may not exceed 100psi at any point. Negative pressures are never allowed.

The pressure at the wheat fields must be at least 10 psi to support spray irrigation in this area.

The pressure at the cotton fields and corn fields must be at least 4psi to support the automated dripline systems.

Key Comparative Analysis: Low-speed vs. High-speed

Assume a design velocity in the case of low-speed operation to appropriately size your pipes and pump specifications. Experiment until all design constraints are satisfactorily

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[1] MAGNET4WATER ConduitNET utilizes the EPANET open source code developed by the US Environmental Protection Agency (EPA) to compute the flow dynamics in a pressurized pipe system like the one described in this project.

addressed. Complete a cost analysis using the built-in tool available in ConduitNET (see more in Detailed Instructions), considering both construction costs and energy costs (as well as other upfront or ongoing costs).

Then, assume a new design velocity in the case of high-speed operation to repeat the process: re-size your pipes and pump specifications to meet all design requirements, and complete a cost analysis. Compare the two design scenarios and discuss the implications in terms of different types of costs or other considerations (social, environmental, etc.).

TECHNICAL DETAILS

1. Water Demand Calculations

Calculate the total annual water demand for irrigation. This is the sum of the water demand for growing wheat, cotton and corn in their respective fields shown in Figure 2. The water demand and farm area for each crop is shown in the Table below.

Note that 1 acre is 43,560 ft^2 and an acre-foot is the volume of water that occupies 1 acre of land, 1 foot deep. A cubic foot per second (cfs) is equal to 723.97 acre-foot per year.

The total annual water demand is to be used as the design flow for pipeline and pump station design.

Crop	Water Demand (ft per acre per year)	Farm Area (square ft)
Wheat	2.9	3,397,680,000
Cotton	4.1	2,809,620,000
Corn	2.4	4,247,100,000

2. "Horizontal Collector System" and Lift Pump Station

One key challenge of utilizing freshwater reserves along the Indus river is the significant bank erosion / shifting course of the main channel. Traditional wellfields consisting of pump stations situated directly on the riverbanks today may become inaccessible in the future due to long-term erosion or periodic flooding.

An innovative approach has been put forth that uses a series of collector pipes to move water from the riverside groundwater wells to a pumping station location ≈1.5km from river's edge, safely away from sensitive riverbanks and out of the 500yr flooding zone. The collector pipes are situated below the water table and take advantage of gravity-driven flow to pressurize the pipes until the water reaches the "lift" pump stations.

Use ConduitNET to evaluate the feasibility of the proposed approach.

The riverside groundwater wells can be represented as a Reservoir features in ConduitNET with a Total Head equal to the water table elevation in the area, which averages 295ft (about 15ft below land surface).

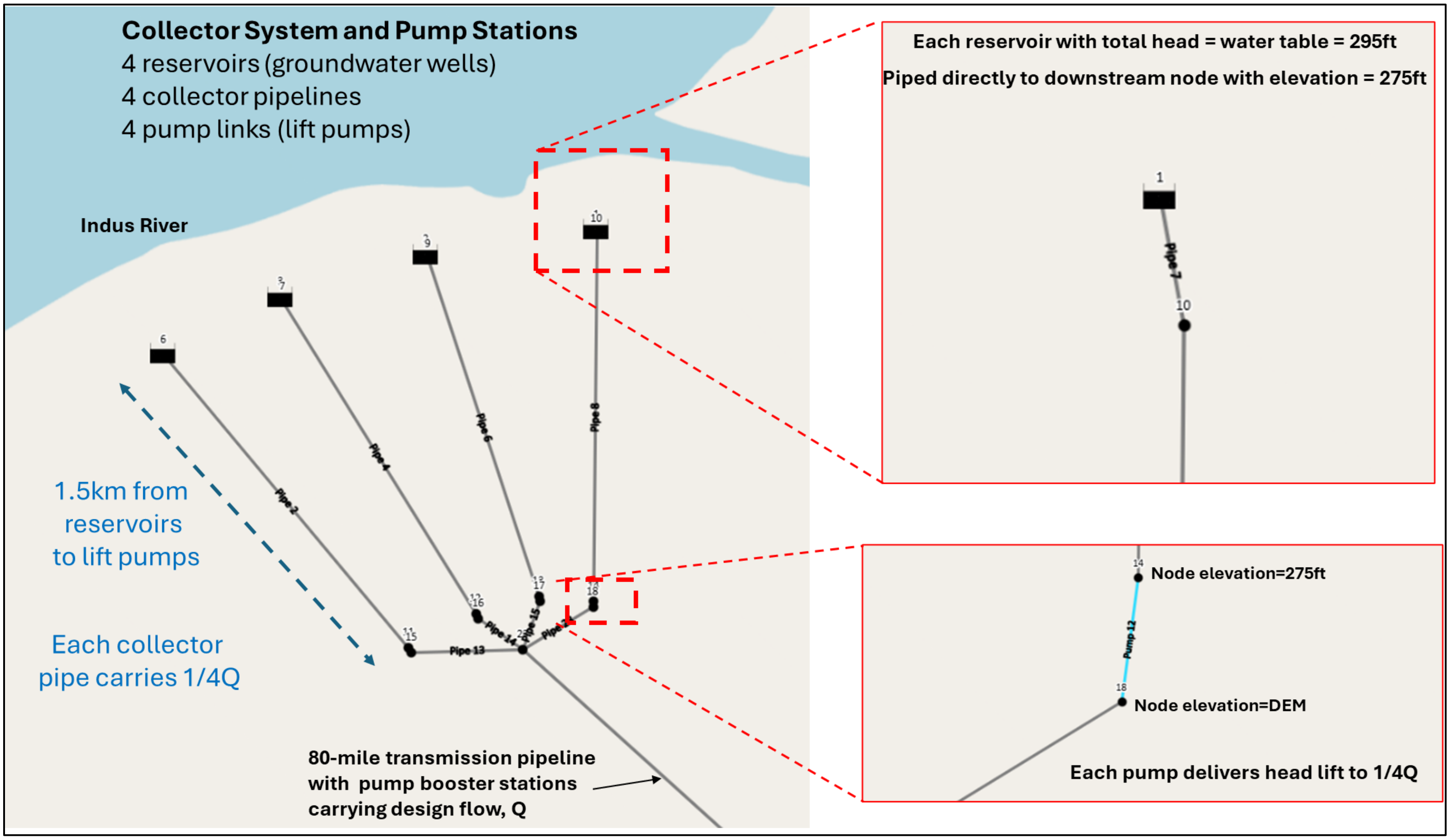
The design calls for 4 wells (Reservoirs) to be placed along the stretch of the Indus River, 4 series of collector pipes, and 4 lift pumps (see figure below).

- Each reservoir should be linked via pipe to a Junction with an elevation of 275ft. These Junctions represent the intake pipes situated 20ft below the water table.
- Each Junction should be linked (via a pipe) to another junction ≈1.5km (0.9 mile) away from the river. These off-river junctions also have a design elevation of 275ft.
- A pump (pump link) is situated between the first off-river junction (elev.=275ft) and a new junction at the surface (elevation=DEM).
- Assign a pump curve for each pump link using 1/4Q, where Q is the design flow or total drop water demand computed above. Experiment with a head lift (pump power) that delivers an appropriate pressure to the downstream flow (remember the pipes cannot exceed 100psi or 230 ft head)
- The ConduitNET software allows users to specify the power of a pump or alternatively the design flow and design head of the pump; for example, a user can specify the head gain required at the design flow (i.e., the design operating point).
- Later, after adding the pump booster stations and the rest of the 80-mile transmission line, it may be necessary to adjust the Pump Curve associated with the wellfield Pump links to ensure that enough head to gained to lift the water and "push" it downstream with enough pressure (see next Section).

After the pumps, use a "collector" junction to merge into one large transmission pipeline.

- Experiment with collector pipe diameters and roughness (based on assumed material type) that meet design velocity and pressure requirements

NOTE: use the 'Add DEM' tool in ConduitNET (PROJECT > Add DEM) to assign land surface elevations to all nodes (junctions, reservoirs) in the model. (This is the case for all nodes downstream of the lift pumps). Do not forget to manually change to total head for the reservoirs and design elevations for junctions upstream of the lift pumps (anytime after Add DEM is used).



3. Transmission Line Design

A 80-mile pipeline connects the pumping station to the desert area to be converted to farmland. A booster pump station MAY BE needed along the route (depending on your design) to ensure pressure in the pipeline and at the delivery points (the farm plots) is adequate.

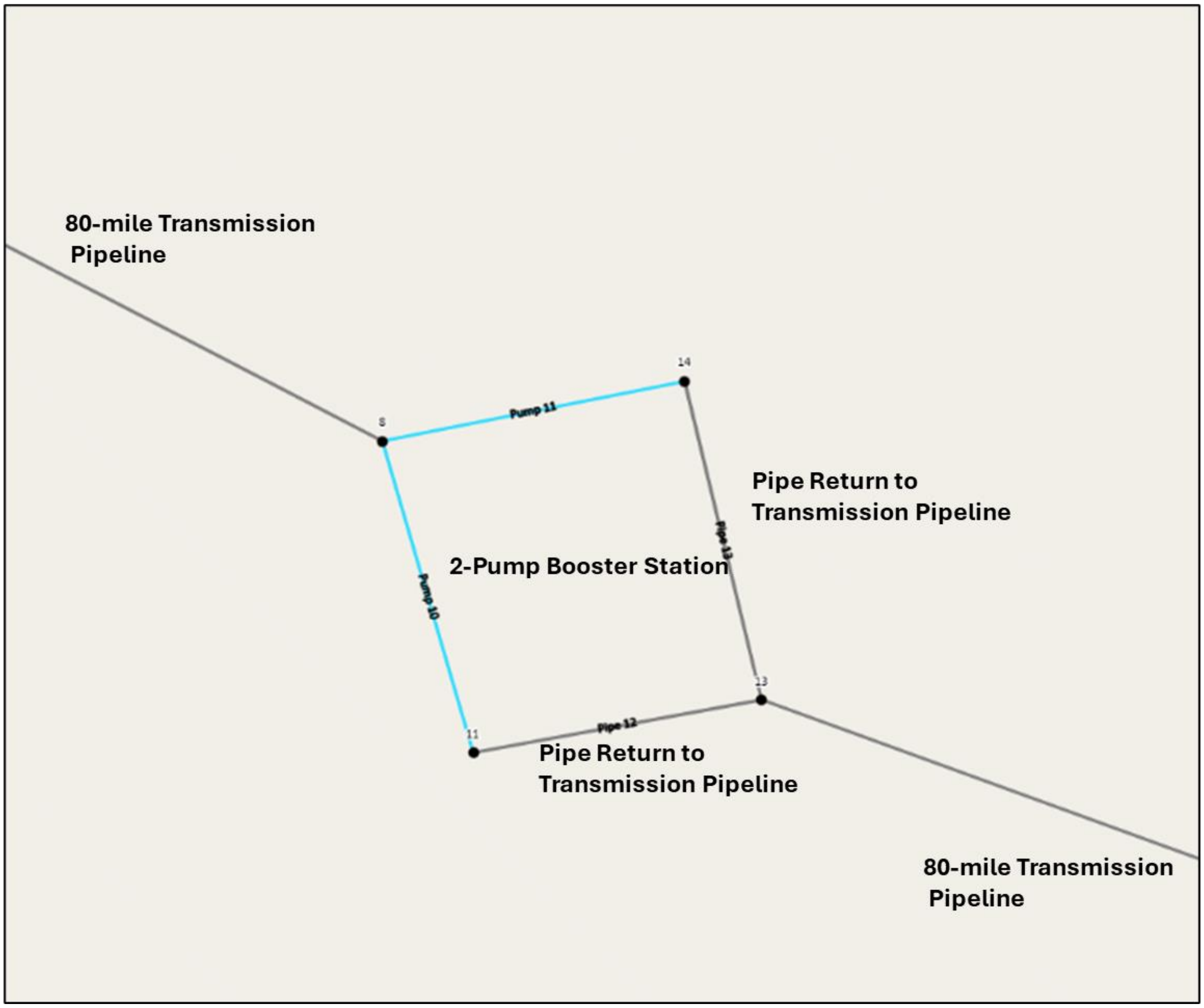
Continue developing the ConduitNET model created in the previous Section to design and analyze the pump stations needed along the route. The key aspects to determine are: i) the distance between booster stations / the number of booster stations required; and ii) the Pump Curve (performance specifications) to utilize for each booster Pump link.

The main transmission pipeline should utilize the diameter calculated from the design velocity, although this design parameter may be changed as part of design optimization in ConduitNET. Assign a roughness that is consistent with the pipe material selected.

The booster stations use different types of pumps than the wellfield lift pumps, so a new Pump Curve should be assigned for the booster station Pump Links. The pump performance (head gain at design flow) may need to be optimized as part of the design process,

Place one or more booster stations along the route to the Junction at the end of the transmission line that “splits” the flow to the three farm areas (wheat, cotton, and corn fields). The final nodes (Junctions) in each field should have the appropriate water demand assigned.

All stations should be linked with a Pipe link that has the characteristics of the transmission line (design diameter, roughness based on material type).



4. Iterative Simulation, Analysis, and Design

Run the model under design flow conditions. Note that the Demand Pattern should utilize a multiplier of 1.0 for all simulation periods.

Post-simulation – analyze the flow dynamics in the pipe network. Use the visualization and analysis tools to inspect the model results, e.g., color-coded map display, time series or profile charts and tables, and 3D visualization – to analyze the pressure and velocity at different places along the transmission line. Do the results make sense? Are the pressures within acceptable ranges?

Refine and improve the ConduitNET model as needed to satisfy all of the design requirements:

- Experiment with pipe diameters and roughness (based on assumed material type)
- Experiment with pump specifications (head lift or power)

5. Cost Analysis

Use ConduitNET's built in Cost Analysis tool to automatically calculate the costs based on the current model: Project > Cost Analysis

The financial cost modeling capabilities include:

- energy cost modeling
- life cycle cost analysis (present value of life cycle energy costs)
- construction cost pipelines
- construction cost pump stations
- construction cost of storage tanks
- right of way costs

The tool calculates pipeline costs using several different empirical methods, based on extensive contract bidding statistics in water resources/ water supply industries in the United States for a wide range of water works projects, including projects involving water pipelines, pipe networks, well fields, and pump stations.

Use the detailed Cost Analysis outputs and capabilities to compare low-speed to high-speed operation and discuss implications in terms of upfront costs vs. ongoing costs.

NOTE: it may be useful to utilize "back-of-the-envelope" cost calculations and verify/compare with more sophisticated design and analysis software cost estimates. An Excel spreadsheet or similar tool is recommended to facilitate the back-of-envelope calculations.

HONORS OPTION

For students looking to complete an Honors Option for the project, please complete the following *additional* tasks/analyses:

1. Prepare and analyze an additional design scenario that ensures 24/7, 365-days-a-year availability of water for crop production (e.g., adding a 2nd or dual transmission lines with dynamic operation). What are the cost implications?
2. Evaluate the feasibility of increasing the buffer intake length (off-river distance of the pump stations) to more than the proposed 1.5km. What are the cost implications?