DEWATERING AND CONTAINMENT OF HEAVY-METAL CONTAMINATED SEDIMENTS WITH GEOTEXTILE CONTAINERS AND POLYMERS. DEVELOPING AND VALIDATING SYSTEM PERFORMANCE AND DESIGN

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ABSTRACT

The processing and refining operations at a former mine site in Eastern Canada resulted in significant environmental impact, leaving behind high concentrations of harmful materials such as arsenic, cobalt, copper, nickel, and low-level radioactive material in soil, sediment, surface, and groundwater. To reclaim the site, a project was undertaken to develop and validate a hydraulic process to remove, contain, and dewater contaminated sediments efficiently and effectively, while reducing the handling of material.

The project design included dredging, geotextile containment and filtration, polymer conditioning, pH adjustment, and filtrate management. Geotextile containers provide a reliable, cost-effective way to collect, dewater, and permanently store contaminated sediment on or near the site. The technology has been successfully used for mine reclamation operations and other environmental remediation projects worldwide. The addition of polymers to the dredged slurry can enhance the retention of heavy metals and other contaminants, while also improving the sediment's dewaterability. The combination of polymer and filtration provided by the woven geotextile produces low total suspended solids in the effluent and is ideal as a pretreatment step allowing for filtrate to be managed separately according to its characteristics. The filtrate produced by the geotextile containers is often suitable for direct discharge to a receiving body.

The paper discusses each step of project development, including bench-scale testing, on-site pilot testing, and the full-scale concept. Performance data is presented on the sediment removal rate, the attained solids of the material, the retention of heavy metal contaminants in dewatered sediment, and the quality of the filtrate produced by the process. The data collected during this preliminary stage informed the design of a large-scale project to dredge, dewater, and permanently store a significant volume of contaminated sediments from the site, while returning treated effluent that met discharge requirements.

Keywords: Mining, sediment, remediation, contamination, geotextiles, dewatering

INTRODUCTION

Many water bodies have been impacted by the release of pollutants that are produced during mining activities and other industrial processes. These pollutants can include metals, hydrocarbons, volatile organics, polychlorinated biphenyls and others. The long-term discharge of these contaminants can cause accumulation in the sediments of a water body and negative impacts to aquatic organisms, terrestrial plants and animals, and even humans.

Remediation of the impacted water body often involves removal of the contaminated sediments from the water body and then onsite containment of the sediments or relocation to a disposal site. This paper will present a step-by-step process used at a former mine site to validate and scale up a simple low-energy process that uses Geotube™ geotextile containers and polymers for dewatering and containment of dredged contaminated sediments. Considerations for filtrate treatment, Geotube stacking and permanent onsite storage of the filled Geotubes will also be discussed.

SEMI-PASSIVE DEWATERING WITH POLYMER CONDITIONING AND GEOTEXTILE CONTAINERS

Geotextile containers have been used for decades to collect and dewater many types of granular and organic slurried materials at operating and non-operating mines, environmental remediation projects and many industrial applications. The Geotube geotextile containers discussed in this paper incorporate GT500 material, which is made from a woven polypropylene yarn. This fabric provides durable containment and a permeable structure with nominal pore size of 420 microns to enable rapid dewatering and filtration. Polymers are carefully selected and dosed into the sludge feed line as the material is pumped to the geotextile containers.

Figure 1. Geotube GT500 material (left) is made from woven polypropylene yarn that provides strong containment and a permeable structure (nominal pore size of 420µm) for rapid dewatering and filtration.

Slurried materials are pumped to the containers through a 152-mm or 203-mm (six- or eight-inch) feed line, which enables pumping at rates of up to 2,000 litres (528 gallons) per minute. The system can achieve faster pumping rates by using a manifold system to feed multiple containers simultaneously.

The polymer enables flocculation of fine particles such as silt or clay, enhances the release of water and aids in the retention of contaminants, such as metals, suspended solids, organics, and more. An optimized chemical conditioning process can produce high quality filtrate that reduces loading to subsequent water treatment processes. Depending on the conditions and treatment requirements, the filtrate may also be suitable for onsite reuse in a non-potable application or direct discharge to a receiving body.

This semi-passive, gravity-based approach offers an alternative to mechanical dewatering options, such as centrifuges and belt presses. These mechanical methods are well suited for space-constrained sites due to their compact footprint. However, mechanical options require considerably more energy to operate and have a lower sludge feed rate, typically only a few hundred litres per minute. If higher processing rates are required, multiple centrifuges or belt presses need to be deployed at a site.

A Geotube dewatering system operates predominantly by gravity, which makes it less complex and more energy efficient than mechanical options. The containers are available in many sizes ranging from small units that can be set up in roll off bins to units that can be up to 91 m (300 feet) long. The size of the containers is customized to suit the available space for a deawatering cell and the estimated volume of solids. The containers can also be stacked to reduce the size of the dewatering cell.

Figure 2. Multiple sizes of Geotubes enables customized dewatering applications ranging from roll-off bins (left), single-layer cells (centre) and stacked configurations that can be several layers high.

PROJECT DEVELOPMENT – PERFORMANCE TESTING AND SCALE UP

Several tests can be performed as part of the project development process to demonstrate the performance of Geotube dewatering and polymer conditioning and to improve the accuracy of estimating project cost, duration and outcomes. These parameters include, polymer selection, the volume of polymer that will be required, sludge density, the estimated volume of in situ or process material, the dewaterability of the material, the quality of the filtrate released from the Geotubes, and the total dewatered volume of the material. Additional testing can also be performed to identify parameters of concern and evaluate the system's ability to retain the contaminants in the Geotube. An analysis of the filtrate enables a project team to address any additional treatment of the filtrate to remove contaminants prior to releasing the treated effluent to the environment or potentially reuse of the water in a non-potable application.

The following sections outline tests and results to evaluate the Bishop Solids Management Solution, which incorporated Geotube dewatering and polymers, for a remediation project in Eastern Canada. The project aimed to develop a low-energy, cost-effective process to remove sediments from a river that were contaminated with arsenic, cobalt, copper, nickel and low-level radioactive uranium. Although the mine was no longer operating, the sediments had accumulated over many years while the mine was in production.

BENCH-SCALE TESTING

Bishop Water's bench testing begins with a 20L sample of material. Occasionally additional samples are needed to capture variations in the sediment material that may occur at different locations. The sediment samples may be tested individually, or they may be blended to create a representative composite sample. In this case, multiple sediment samples were blended and diluted to a slurry with a solids concentration of almost six percent. Jar testing is then performed to determine the optimal polymer, or combination of polymers to achieve the most effective flocculation and settling of the slurried sediments.

Figure 3. At left, several samples of material for testing. The image on the right shows a raw sample (jar at left) followed by flocculation after polymer addition, and a sample of the filtrate from the Geotube.

Once a polymer was selected, a rapid dewatering test (RDT) was performed. In that test, a 200 ml sample of the sediment was treated with the preferred polymer, then poured into a cone that was fitted with a GT500 geotextile filter disk. The filter disk retained the material and allowed filtrate to pass (by gravity) into a beaker below. The volume of water from the sample was measured after one minute, after one hour and after 24 hours.

Table 1 shows the results of the RDT testing. The solids concentration increased to 25.35% and filtrate TSS was very good at 36 mg/L. The arsenic level in the filtrate was 6.03 mg/L, which was excellent when considering that the influent arsenic concentrations were as high as 9,800 mg/L. However, the level was still above the regulatory limit for arsenic in treated effluent, which was 0.1 mg/L, so additional treatment would be needed to reduce the concentration to an acceptable level.

Table 1. RDT results for composite sample of contaminated sediments

Composite sample of contaminated sediments	
Raw slurry solids concentration	5.88%
Attained solids after 24 hours	24.35%
Filtrate TSS	36 mg/L
Arsenic TSS	6.03 mg/L

The next test was a Geotube dewatering test (GDT), which uses a small version of a Geotube container. This unit can process about 100 litres (26 gallons) of slurry and is more representative of a large-scale system. Several different types of sediments were analyzed in the GDT, which represented the various sediment types from the river. The samples were diluted with water, conditioned with polymer, then poured into the GDT container through a fill pipe. The slurry was allowed to dewater for 24 hours before being analyzed. Table 2 shows the results of the testing, which achieved good results for TSS and for dewatering, which ranged from 23.4 to 38 percent solids.

Figure 4. A sludge cake produced by the RDT (left). A technician pours slurry into a GDT container.

Arsenic retention improved significantly in the GDT and was approaching the regulatory limit for discharge. Although the site did have a small onsite water treatment system capable of precipitating out the remaining arsenic, it did not have sufficient capacity to handle the treatment needs for a full-scale cleanup of the site, so an additional system would be needed.

Table 2. GDT results for composite sample of contaminated sediments

	Dry weight 1:1	Dry weight 1:2	Attained solids 24 hrs	TSS filtrate (mg/L)	Arsenic filtrate (mg/L)	Arsenic of raw diluted (mg/L)
Red tailing	14.8%	6.28%	31.7%	28	0.715	9,410
Peat/red mud	10.82%	5.38%	23.4%	70	0.471	8,550
Peat/organic	6.26%	2.66%	26.0%	12	0.210	600
Clay/peat/red mud	15.6%	6.88%	6.88%	20	0.999	6,230

ONSITE TREATMENT DEMONSTRATION

Following the encouraging results obtained in the lab, Bishop Water moved ahead to demonstrate the performance of a pilot-scale dewatering system at the site. This was comprised of two watertight roll-off bins that could each hold a Geotube with a capacity of about 23 cubic metres (30 cubic yards). The bins were equipped with camlocks and pumps that facilitated the removal of Geotube filtrate.

The contaminated sediment was removed from the river with an excavator and deposited in a third bin that was used as a slurry box. Water was added to the bin to fluidize the sediment, then it was pumped to the Geotubes in the adjacent bins. Samples were excavated from several areas of the river to ensure the pilot test accounted for the variability in the amount of clay, mud and organic material. This would enable the team to test the polymer conditioning and Geotube filtration with all anticipated sediments, optimize the process and demonstrate its performance.

Figure 5. A pilot system was set up to demonstrate onsite polymer conditioning, dewatering and filtration with contaminated sediments as they were removed from the river.

Unfortunately, during the pilot test the area was experiencing a drought and the team was not able to draw water from the river to dilute the samples to a slurry and for polymer make down. Water storage tanks were installed at the site and water was trucked in for the pilot. However, the low TSS filtrate that was released from the Geotubes was ideal for reuse so it was pumped back to the water tanks and reduced the amount of water that needed to be hauled to the site.

The polymer system and flocculator was contained in a small trailer and powered by a gas generator. This compact system, called the Venturi Emulsion Polymer Activation System (VEPAS) mixes and activates polymer in a single pass and injects it directly into the feed line. The flow and dose rate can be manually or automatically controlled and it can be equipped with sensors that enable it to adjust dosing in response to changes in flow rate and solids concentration. The image on the right of Figure 6 shows the simplicity of the system. Since there are no mixers or aging tanks the VEPAS requires little maintenance and can be cleaned after use in less than an hour.

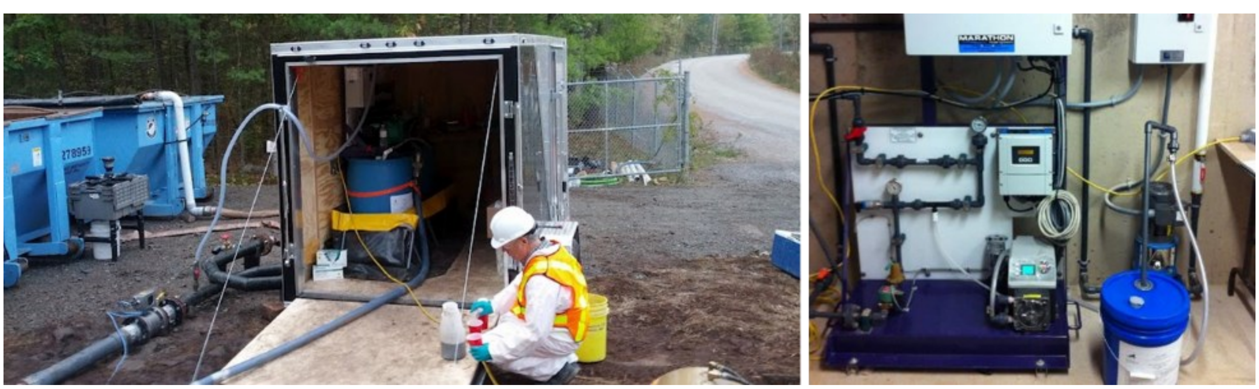

Figure 6. A small trailer (left) contained the polymer dosing system and flocculator for the pilot test. The VEPAS (right) incorporates few components and provides simple polymer activation and dosing.

During the pilot project, the filtrate was also tested to measure dissolved contaminants and determine what treatment would be needed to achieve effluent that could be safely discharged to the river. In addition to arsenic, there were several other constituents of the wastewater that had regulated limits for discharge. These are shown in Table 3.

Table 3. Discharge criteria for treated effluent from the sediment dewatering system

Parameter	TSS	Arsenic	Cobalt	Copper	Nickel
Discharge limit	25 mg/L	0.1 mg/L	49 µg/L	20 µg/L	37 µg/L

Thirty samples were subjected to various tests to determine the most effective treatment process to precipitate the metals from the filtrate and achieve the required discharge limits. The tests included the addition of lime slurry and rapid mixing to raise the pH to 10, then ferric chloride or polyaluminum chloride was added, mixing occurred again, followed by settling. The results are shown in Table 4 and demonstrated that the discharge limits could be achieved with additional treatment of the filtrate.

Table 4. Testing of Geotube filtrate to determine required treatment for discharge compliance

Date	Description	Temp - field (^oC)	pH - field	pH – lab	Arsenic (mg/L)	Cobalt (mg/L)	Copper (mg/L)	Nickel (mg/L)
10/02/12	Day 1 comp raw	13.5	6.1		0.3140			
10/02/12	Day 1 Comp LIME only	13.5	9.5	10.30	0.0154	0.0231	0.0026	0.0126
10/02/12	Day 1 comp 250 ppm PAC	13.5	7.3	7.59	0.0151	0.0091	0.0017	0.0083
10/02/12	Day 1 comp 500 ppm PAC	13.5	7.0	7.61	0.0136	0.0191	0.002	0.0144
10/03/12	Day 1 comp 500 ppm $FeCl_3$	17.0	8.5	8.67	0.0043	0.0013	0.0001	0.0049
10/03/12	Day 1 comp 1,000 ppm $FeCl_3$	17.0	7.3	4.54	0.0035	0.205	0.0021	0.059

The test results from the onsite Geotube pilot system and the filtrate water treatment testing showed that a full-scale system could be scaled up and meet the project requirements. The Bishop Solids Management Solution could reliably collect and dewater solids, while retaining a significant amount of contaminants in the Geotube. The filtrate could also be handled with an onsite water treatment system sized to handle the volume of water and achieve the required discharge limits.

FULL-SCALE SETUP AND OPERATION

A full-scale demonstration system was set up by Bishop Water to collect and dewater several thousand cubic metres of sediments from the river. The setup included a lined dewatering cell sloped at 0.5% grade towards a lined trough to collect the filtrate. The Geotubes were unrolled in the dewatering cell and connected to the feed lines. A trailer-mounted VEPAS polymer system and flocculator was used to control the mixing, activation and dosing of the chemical conditioning directly into the feed line.

Seven Geotube containers were used to collect and dewater contaminated sediment that was removed by a cutterhead pump mounted on an excavator and pumped at an average rate of 1,800 litres (475 gallons) per minute. The GDT was performed periodically with in situ treated material to verify the composition of the sediments and ensure optimal performance of the polymer conditioning and dewatering.

Four Geotubes, 36.5 m (120 ft) in circumference and 56.7 m (186 ft) in length were initially laid out in the dewatering cell, followed by three more of the same size, which were stacked on top of the first layer.

Figure 7. The full-scale demonstration project included a lined dewatering cell that held seven Geotubes, 120 ft circumference by 186 feet in length (left.) A larger, containerized polymer system was also brought to site. Over the duration of the demonstration project, the crew dewatered 24,905.5 m^3 (32,575 yd^3) of contaminated sediments, which corresponds to 1,789.07 bone dry tonnes (1,972.11 bone dry tons).

WATER TREATMENT SYSTEM

As the filtrate was released from the Geotubes, it was collected in a trench, then pumped to an onsite water treatment system, which was developed and operated by Bishop Water. The system was once again a scaled-up version of the bench testing that was done in the earlier stages of the project. The water treatment system was brought to site in a 6 m (20 ft) shipping container and connected to the feed line from the filtrate collection system in the Geotube dewatering cell.

Figure 8. A diagram of the water treatment system (left) and the 6 m container that housed the components.

The system followed the protocol that was developed in the testing steps. Lime was first added to raise the pH to 10, then polyaluminum chloride was added to precipitate the metals. A VEPAS system was also installed in the water treatment container and was used to add polymer to the precipitated metals. This would further consolidate the solids and allow them to settle faster in a series of weirs that functioned as clarifiers for the treated effluent. The clarified water then flowed to a collection tank where the TSS was measured by an inline meter to ensure compliance before discharge.

Figure 9. The components of the water treatment system included a mixing tank and peristaltic pumps (left) and a control panel, flocculator and flow meters (right).

Table 5. Results from water treatment system shows compliance with discharge limits.

	Arsenic (mg/L)	**Cobalt (mg/L)**	**Copper (mg/L)**	**Nickel (mg/L)**	**TSS (mg/L)**	**pH**
June 15 avg. influent	1.22	0.026	0.014	0.024	6.38	7.67
July 15 avg. influent	1.08	0.015	0.017	0.019	2.14	8.09
Aug. 15 avg. influent	1.29	0.020	0.031	0.022	13.62	8.13
Effluent limit	**0.1**	**0.049**	**0.02**	**0.037**	**25**	**6.5-8.5**
June 15 avg. effluent	0.027	0.006	0.004	0.010	7.62	7.82
July 15 avg. effluent	0.032	0.003	0.005	0.007	6.64	8.09
Aug. 15 avg. effluent	0.033	0.002	0.006	0.005	6.23	7.95

HYDROCARBON TREATMENT

The Bishop Solids Management Solution and supplementary water treatment has also been effective to remove sediments that are impacted with hydrocarbons and produce treated effluent that meets discharge requirements.

One example is from Quebec where about 2,000 m^3 (2,616 yd^3) of sediments contaminated with hydrocarbons were removed from a river, conditioned with polymer and dewatered using the Bishop Solids Management System. The TSS of the filtrate was consistently below 7 mg/L, which was well within compliance of the 25 mg/L discharge limit.

Hydrocarbons were removed from the filtrate using an onsite carbon filtration system which reduced the concentration to less than 10 µg/L and enabled the effluent to be discharged back to the river. The dewatered sediments were removed from the site and disposed of in a suitable landfill.

Figure 10. A Geotube dewatering cell (left) designed to dewater and contain contaminated sediments. A carbon filter system (right) was installed to remove hydrocarbons from the Geotube filtrate.

PERMANENT ONSITE CONTAINMENT OF CONTAMINATED SEDIMENTS

In some cases, Geotubes that are filled with contaminated sediments remain at a site and can be incorporated into landscape features or become part of a development project. Depending on the type of material, the contaminants and the location of the storage cell, a leachate collection system might also be incorporated.

At Onondaga Lake, New York, over 1.7 million m^3 (2.22 yd^3) of contaminated sediments were dredged from the lake and pumped into Geotubes. The material included contaminants such as mercury, volatile and semi-volatile organic compounds, polychlorinated biphenyls and hyperalkaline inorganic materials. These had accumulated as a result of many decades of industrial discharges into the lake.

In the initial stages of the project, over 160 polymers were evaluated and the top three performers were selected for the full-scale chemical conditioning of the sediments. Once the project was underway, three hydraulic dredges pumped sediments from multiple points in the lake, with the farthest being almost 6.5 km (4 miles) from the dewatering cell. Booster pumps helped convey the slurry and the system ran at a rate of almost 960 m^3 (1,255 yd^3) per hour, 24 hours per day, for about two and a half years.

Upon completion, 979 Geotubes had been filled and stacked up to five layers high in a cell that was 22 hectares (55 acres) in area. The cell was then capped with soil, fully vegetated and is now home to a visitors centre that provides education and a hub for continued conservation and restoration projects at the lake.

Figure 11. The Geotube dewatering cell at Onondaga Lake is stacked up to five layers high and occupies about 22 hectares. The image on the right shows the cell once capping was complete and prior to adding vegetation.

GEOTUBE STACKING CONSIDERATIONS.

Stacking Geotubes, whether only two layers or several layers, such as the Onondaga Lake project, is a complex process that requires careful planning and consideration of several factors.

Proprietary software is employed and begins with an evaluation of the volume of material that will be pumped into each Geotube and the stresses that will be exerted on the textile, seams and ports. Next the evaluation focuses on the stability of the dewatering cell and estimates the risk of settling during filling and once the structure is complete.

Table 6. A sample of critical parameters to consider for Geotube stacking

Analysis	Parameters
Geotube stability analysis	Dewatered material unit weight
	Dewatered material cohesion
	Dewatered material friction angle
	Foundation unit weight
	Foundation material cohesion
	Ground water level
	Foundation geological profile – yes/no
Geotube settlement analysis	Bathymetric survey (if installed in water) yes/no
	Saturated unit weight dewatered material
	Unit weight dewatered material
	Saturated unit weight foundation
	Foundation unit weight
	Foundation geological profile – yes/no
	Foundation material cohesion
	Foundation material friction angle
	Foundation compression index
	Foundation initial void ratio

The stability of the structure itself is also evaluated and considers the geotechnical properties of the sediment, the cohesiveness of the material and the shear forces. Ideally the sediments should consolidate well and hold together to avoid exerting stress on the Geotube fabric and increase the risk of containment failure. And finally, a model of the stack is created with the dimensions and location of each Geotube, the number of stacked layers, the quantity of fabric, the liner material and the overall footprint of the dewatering cell.

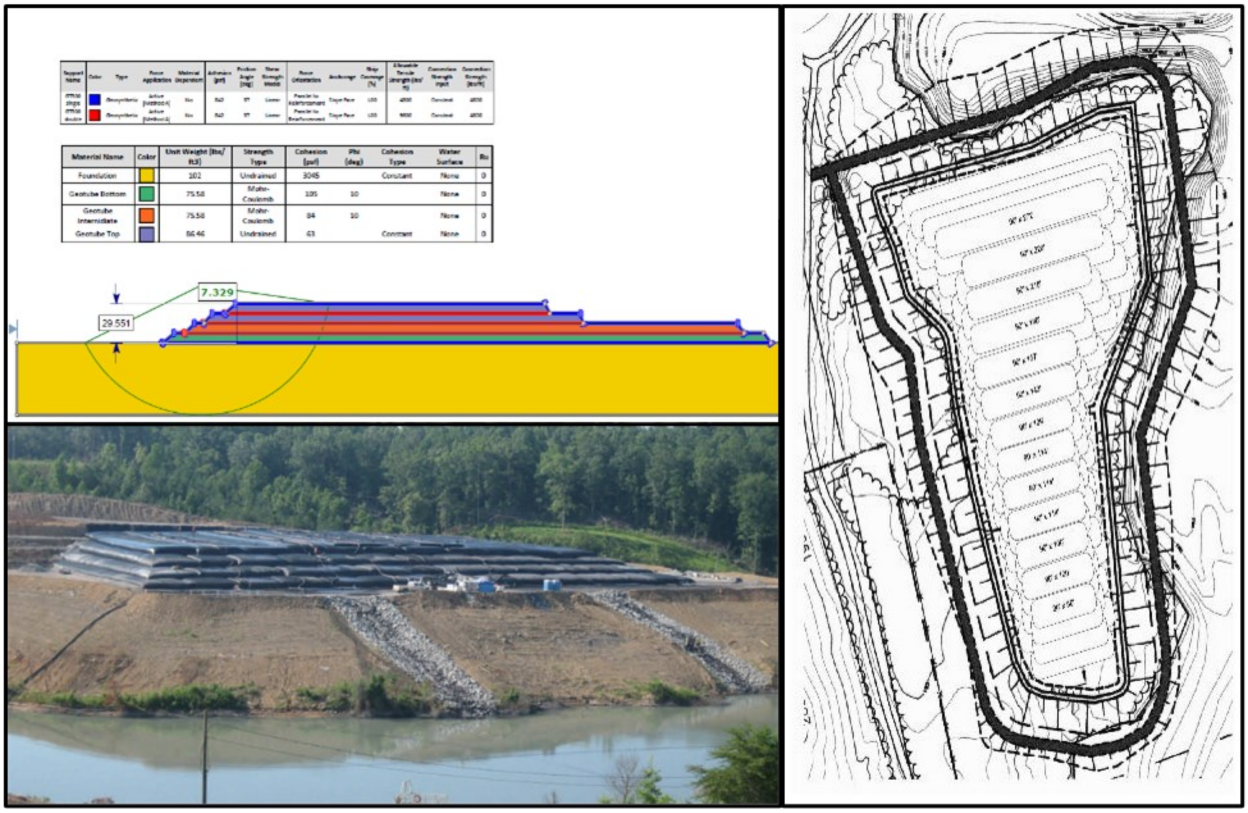

Figure 12. A sample of drawings and calculations that are considered when developing a large-scale Geotube stacking project that occupies a significant area and may incorporate several layers.

SUMMARY

Geotextile dewatering and polymer conditioning provides a simple, cost-effective process to collect and dewater contaminated sediments from impacted sites. The process can also retain contaminants, such as metals, within the dewatered material and produces low TSS filtrate. If required, additional onsite water treatment can remove remaining contaminants, including hydrocarbons and other volatile components, to achieve effluent requirements for non-potable reuse or discharge to a receiving body.

A series of testing and scale-up procedures can effectively demonstrate all aspects of system performance and provide information for full-scale design and process optimization. Once filled, the geotextile containers can become part of a permanent onsite storage system or the contents can be removed and relocated to a disposal facility.