A screening-level cost model for geomembrane-lined pumped storage reservoirs

S. DeNeale, A. Chu and V. Koritarov, Oak Ridge National Laboratory, USA
M. Altinaka, Argonne National Laboratory, USA
J. Hedien, Stantec, USA

Pumped storage is a proven and widely deployed technology for large-scale energy storage and grid reliability. As interest in new pumped-storage development increases (particularly for closed-loop configurations) there is increasing focus on the design and cost of surface reservoirs. Reservoir lining systems play a critical role in minimizing seepage losses, maintaining storage efficiency, and ensuring long-term performance. However, developers often lack practical tools to evaluate alternative lining approaches at early project stages. This paper presents a screening-level cost model for geomembrane lining systems, developed to support early decision-making in pumped-storage reservoir design.

Surface reservoirs used in pumped-storage facilities typically require lining systems to reduce seepage and maintain storage efficiency. Four primary lining approaches are commonly considered: asphalt concrete liners, compacted clay liners, concrete liners, and geomembrane liners.

Asphalt concrete liners are widely used because of their flexibility and ability to accommodate subgrade deformation. They also provide good resistance to environmental exposure but may require periodic maintenance and can be sensitive to temperature variations and cyclic loading.

Compacted clay liners offer relatively low permeability when properly constructed, but they require careful material selection, moisture control, and compaction. Their performance can be sensitive to cracking and desiccation.

Concrete liners provide a durable and robust solution with well established design practices. However, they are typically associated with higher capital costs and may be susceptible to cracking because of thermal or structural stresses.

Geomembrane lining systems (see example below) consist of synthetic polymeric sheets placed over a prepared subgrade and often combined with geotextiles, drainage layers, and protection systems. They offer very low hydraulic conductivity and can be installed relatively quickly. Despite extensive global use in reservoirs, canals, and containment systems,

Mount Gilboa pumped-storage project under construction in Israel. Source: Admir Technologies.

Table 1: Comparison of common reservoir lining systems for pumped storage

Lining system	Typical configuration	Key advantages	Key limitations	Relative cost*
Asphalt concrete (AC/DAC)	Multi-layer system including binder, dense impermeable asphalt layer, and protective seal coat	Flexible; accommodates subgrade deformation; widely used in PSH; good erosion resistance	Sensitive to temperature variations and cyclic loading; potential for blistering; requires periodic maintenance	Medium
Compacted clay liner (CCL)	Compacted low-permeability clay layer placed over prepared subgrade, typically with significant thickness	Low material cost; well understood; widely available materials	Sensitive to cracking and desiccation; requires strict moisture and compaction control; thicker sections required to achieve low permeability	Low to medium
Concrete liner	Cast-in-place or precast concrete slabs placed over foundation or embankment, often with joints and drainage provisions	Durable; high structural integrity; established design practices	High capital cost; susceptible to cracking; requires joints and maintenance	High
Geomembrane liner	Synthetic polymeric membrane (eg. HDPE, PVC) with geotextiles, drainage, and anchoring systems	Very low permeability; rapid installation; adaptable to foundation conditions; potential cost savings	Requires rigorous QA/QC; sensitive to installation defects; limited PSH-specific experience in U.S.	Low to medium

*Relative cost reflects general trends based on available literature and project experience; actual costs are site-specific.

their application in pumped-storage reservoirs (particularly in the USA) has been limited.

A comparison of the primary reservoir lining systems, including key advantages, limitations, and relative cost considerations, is provided in Table 1.

1. Geomembrane liners: Opportunities and challenges

Geomembrane liners have been used internationally for more than six decades and have demonstrated strong performance in water retention applications. Their key advantages include low permeability, adaptability to foundation conditions, and potential cost savings compared with traditional lining methods.

For pumped-storage applications, geomembranes may offer particular benefits in closed-loop systems, where minimizing seepage is critical to maintaining storage volume and reducing makeup water requirements. Their flexibility allows them to accommodate cyclic loading associated with frequent reservoir drawdown and refill.

However, challenges remain. Geomembrane systems require careful installation and rigorous quality assurance and quality control (QA/QC) to minimize defects. Long-term performance depends on proper design of supporting layers, anchoring systems, and protection measures. In addition, limited experience with geomembrane-lined pumped-storage reservoirs in the USA has contributed to uncertainty in cost estimation and technology selection.

2. Development of the cost model

To address the need for improved cost transparency, a spreadsheet-based cost estimation model has been developed to support early-stage evaluation of geomembrane lining systems for pumped-storage reservoirs [DeNeale, Chu, Altinakar, Hedien, and Koritarov, 2026[1]]. The model is designed as a practical, user-friendly tool that provides rapid, screening-level cost estimates while requiring a limited set of input parameters.

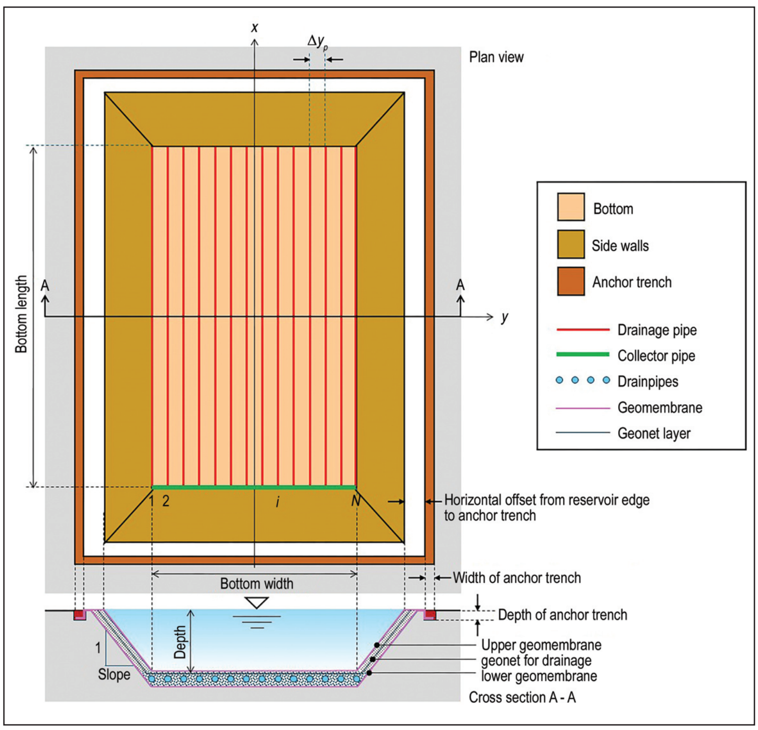

Fig. 1. Parametric representation of reservoir geometry used for cost estimation.

The cost model considers three reservoir geometries: rectangular, circular/elliptical, and non-standard shapes. A representative parametric geometry used in the cost model is shown in Fig. 1. For standard geometries, the model uses parametric inputs to estimate surface areas and material quantities. For non-standard geometries, users can input areas directly based on engineering drawings.

A generic geomembrane lining system template underpins the model. A typical multilayer geomembrane lining configuration considered in the model is illustrated in Fig. 2. This template includes options for single or double geomembrane layers, multiple geotextile layers, cover systems, anchor trenches, and drainage and leak detection systems. Users can activate or deactivate components to represent different design configurations.

To reduce the burden on users, default values are provided for key design parameters and unit costs. These defaults are based on data obtained from geomembrane manufacturers and past engineering projects. Users can override default values to reflect project-specific conditions, enabling flexibility in evaluating alternative designs.

The model calculates material quantities based on selected configurations and applies unit costs to estimate total lining system costs. Outputs are presented in tabular and graphical formats, allowing users to compare different design options efficiently.

3. Application examples

The cost model was tested using three representative case studies reflecting common pumped-storage reservoir configurations. The key characteristics of the representative case studies evaluated using the cost model are summarized in Table 2.

The first case considered a circular upper reservoir, for which multiple geomembrane lining configurations were evaluated, including single and double liner systems and different material types. The results demonstrated how design choices influence overall cost and highlighted the trade-offs between system redundancy and capital cost.

The second case examined a reservoir with a non-standard geometry. This example demonstrated the flexibility of the model in accommodating complex layouts and showed how user-defined inputs can be used to estimate costs when parametric geometry is not applicable.

The third case analysed a rectangular reservoir, with costs evaluated as a function of reservoir volume. This example illustrated the relationship between reservoir size and lining cost, providing insight into scaling effects and cost trends.

Across all cases, the model produced cost estimates consistent with screening-level expectations. The results indicate that the tool can provide sufficiently accurate estimates for early-stage comparisons of lining alternatives, supporting feasibility and pre-feasibility analyses. The relationship between reservoir size and estimated geomembrane lining cost for representative configurations is shown in Fig. 3.

4. Practical implications for pumped-storage development

The developed cost model provides a practical tool for pumped-storage developers, engineers, and planners to evaluate geomembrane lining systems during the early stages of project development. By enabling rapid cost estimation and a comparison of alternative designs, the tool helps reduce uncertainty and supports more informed decision-making.

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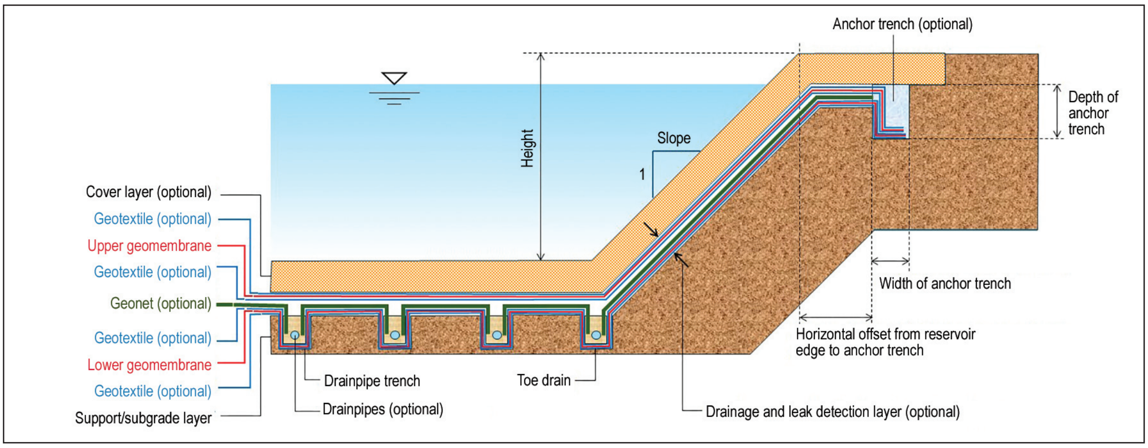

Fig. 2. Typical multilayer geomembrane lining system configuration used in the cost model.

Table 2: Summary of case study reservoir configurations and lining options				
Case	Reservoir geometry	Key inputs	Lining configurations evaluated	Purpose of analysis
Case 1	Circular upper reservoir	Diameter, depth, side slope	Single and double geomembrane systems; HDPE and PVC options; covered and uncovered configurations	Evaluate cost differences across liner types and redundancy levels
Case 2	Non-standard reservoir	User-defined surface areas	Double geomembrane system with drainage and protection layers	Demonstrate flexibility of model for complex geometries
Case 3	Rectangular reservoir	Length, width, depth, slope	Representative geomembrane configuration	Evaluate cost scaling with reservoir volume

The model is particularly useful in screening studies, where multiple design options must be evaluated quickly with limited data. It can also support preliminary design activities by providing initial cost benchmarks that can be refined as project details become available.

Importantly, the tool is not intended to replace detailed engineering cost estimates. Rather, it provides a first-order assessment that can guide technology selection and identify promising design configurations for further analysis.

5. Conclusions

Geomembrane lining systems represent a viable and underutilized option for pumped-storage reservoir applications. While widely used internationally, their adoption in the USA has been limited, in part because of a lack of accessible cost estimation tools and project experience.

The screening-level cost model presented in this paper addresses this gap by providing a practical, user-friendly tool for estimating geomembrane lining costs. Application of the model to representative case studies demonstrates its ability to generate reasonable cost estimates suitable for early-stage decision-making.

As interest in new pumped-storage development continues to increase, tools such as this cost model can play an important role in supporting technology evaluation and project planning.

Future work may build upon this foundation by incorporating additional data, refining assumptions, and validating results as more geomembrane-lined pumped-storage projects are developed. ◊

Reference

1. **DeNeale, S.T., Chu, A., Altinakar, M., Hedien, J., and Koritarov, V.,** "Cost Model for Pumped Storage Hydropower Geomembrane Lining Systems", *HydroSource*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA. DOI: *https://doi.org/10.21951/PSHgeomembrane/3028450*; 2026.

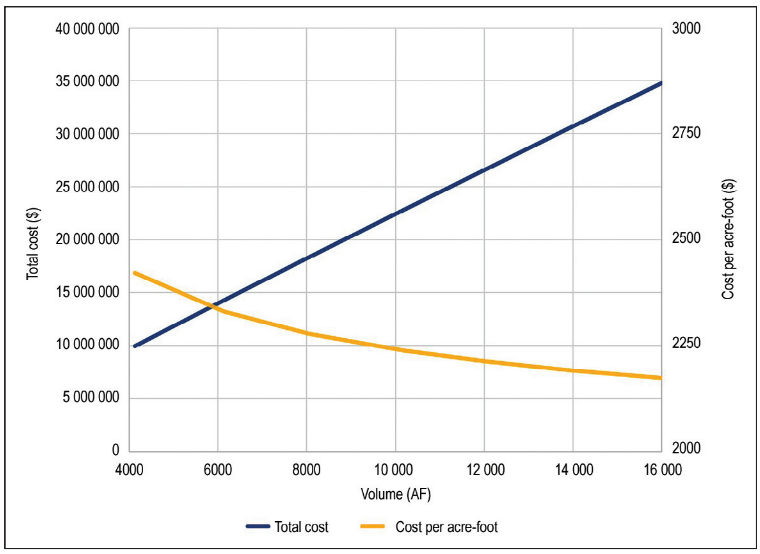

Fig. 3. Estimated geomembrane lining cost as a function of reservoir volume for representative design cases. Costs are reported in 2024 US dollars.

S. DeNeale

A. Chu

V. Koritarov

M. Altinakar

J. Hedien

Scott DeNeale is a Water Resources Engineer (EIT) Research Staff in Oak Ridge National Laboratory's (ORNL's) Environmental Sciences Division, conducting a wide variety of applied research projects at the largest science and energy national laboratory in the USA. He has specialized experience in hydrologic and hydraulic (H&H) modelling, water resources engineering, environmental and economic data analysis, and project management, with application to water-energy systems. He joined ORNL in March 2013 and is currently primarily involved in hydropower and pumped-storage research, hydropower technology and cost modelling research, and precipitation and flood modelling.

Antonia Chu is a Water Resources Engineer in the Water Resource Science & Engineering Group at Oak Ridge National Laboratory (ORNL). Her work focuses on next-generation hydropower systems, including conduit hydropower, new stream-reach development, and pumped-storage applications. She conducts large-scale geospatial and data analyses to support hydropower research across the USA. Before joining ORNL, she worked on domestic and international projects with a focus on flood prevention planning and engineering design, and modelling sustainable and economic reservoir sedimentation management.

Vladimir Koritarov is the Director of Electric Power Systems department at Argonne National Laboratory and Programme Manager for Argonne's water power program. He has more than 35 years of experience in the modelling and analysis of electric and overall energy systems in domestic and international applications. His research interests include the analysis of power system capacity expansion options, modelling of hydropower and pumped-storage systems, hydro-thermal coordination, reliability and production cost analysis, integration of variable renewables, energy storage, electricity markets and electric sector restructuring issues. He has managed numerous energy and environmental projects and provided technical assistance to more than 30 countries. Before joining Argonne in 1991, he worked for eight years as power system planner in the Union of Yugoslav Electric Power Industry.

Oak Ridge National Laboratory, 1 Bethel Valley Rd No 5200, Oak Ridge, Tennessee 37830, USA.

Mustafa Altinakar is the Senior Computational Hydroscience Engineer in Decision and Infrastructure Sciences Division at Argonne National Laboratory. Before joining Argonne, he served as Director and Research Professor of the National Centre for Computational Hydroscience and Engineering (NCCHE) at the University of Mississippi and as Acting Director of Hydraulic Research Laboratory (LRH), Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland. Working as a Senior Design Engineer in a Swiss consulting company, he took part in many large-scale projects, including dams, hydropower plants, flood protection schemes, drinking water supply and waste-water collection networks. His research interests include fluvial hydraulics/sediment transport, flood simulation/mapping, natural hazards, infrastructure and community resilience, transport and fate of contaminants, stratified flows, computational fluid dynamics, integrated watershed management, optimization and decision support systems, design of hydraulic structures, climate change and its impact on infrastructures and communities. He developed the DSS-WISE web-based dam-break flood simulation system, currently used by FEMA and state dam safety offices, for which he received the 2019 Terry L. Hampton Medal from the Association of State Dam Safety Officials (ASDSO). He is the co-author of two books on hydraulics and more than 150 journal and conference papers.

Argonne National Laboratory, 9700 S. Cass Avenue, Lemont, Illinois 60439, USA.

Jason Hedien is a Principal Geotechnical Engineer and Vice President at Stantec with more than 32 years of experience in the management, inspection, analysis and design of dams and hydropower projects, above ground and underground infrastructure, and waterway/port projects. His career has included work on a number of significant dams, conventional hydropower, pumped-storage, and other major civil infrastructure projects throughout the world including the USA, Canada, Panama, Iceland, Türkiye, Peru, and Pakistan. He has experience with asphalt concrete lined, concrete lined, and geomembrane lined reservoirs for both water storage and pumped-storage applications.

Stantec, 350 N. Orleans Street, Suite 8000N, Chicago, IL, 60654, USA.