Overview of the Phase 7 Main Bay Model (MBM) and Multiple Tributary Models (MTMs)

CBP Modeling Quarterly Review

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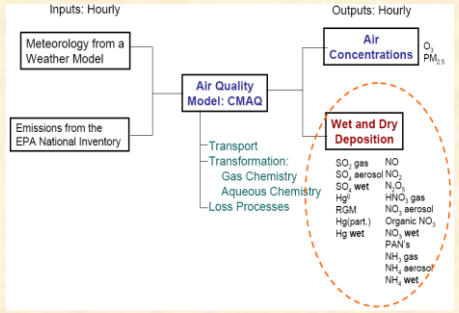
Overview of the Main Bay Model (MBM) Workplan

- The MBM cooperative agreement runs for 6 years: 2022 to 2027.
- The MTMs are yet to be funded or started.
- For both the MBM and the MTMs the CBP Modeling Workgroup gives technical direction and the WQGIT and other CBP decision-making groups will give management and policy direction to MBM practitioners.
- We can partition the MBM and MTM development and application into 5 main tasks:
    - Initial Development (2022 – 2023)
    - Interim Development (2023 – 2024)
    - Final Development (2025)
    - Review and Application (2025-2027)
    - Ongoing tasks.

Phase 7 Integrated Models for 2035 Climate Change Assessment

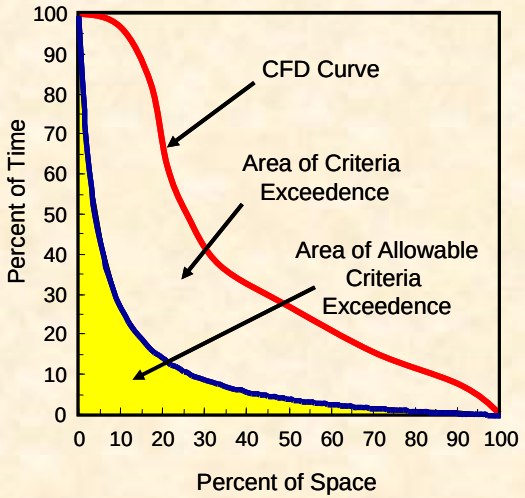
Airshed Model



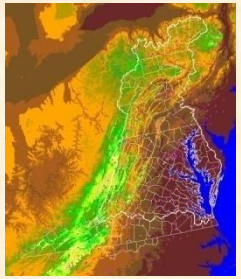
Watershed Model (CAST and Dynamic Model)

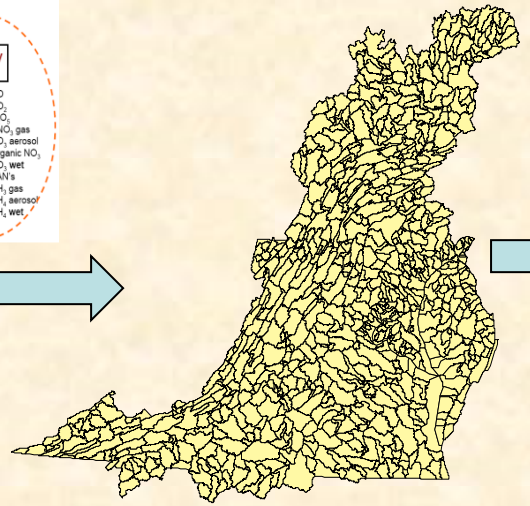
Main Bay Model

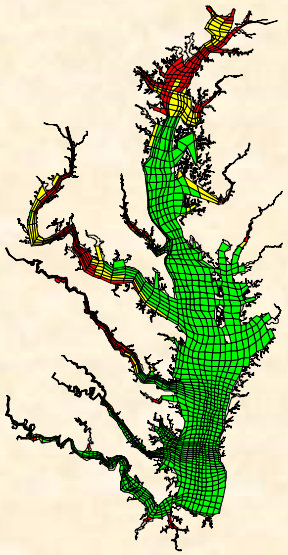
TMDL Water Quality Criteria Assessment Procedures



We have this established plot that we follow. We know what are the important elements are and we know how the story most end, “achieve water quality standards”.







Land Use Model

2035 Climate Effects on Water Quality Standards (WQSs)

Target Loads to Achieve WQSs under 2035 Climate Conditions

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Phase 7 Model Input for MBM From CBP Groups

- WQGIT
  - –October 2021 meeting, voting and comments
- Other GITs – November/December 2021
- STAC
  - –Modeling beyond 2025 workshop (2019)
- Modeling Workgroup - ongoing

Main Bay Model (MBM) and Multiple Tributary Models (MTMs) - Comments and Recommendations

- MBM – improve shallow water simulation for CC, improving problem tribs and incremental attainment. ***Response: This is a necessary task for the Main Bay Model (MBM). However, the shallow water simulation will be further advanced and refined if the Multiple Tributary Models (MTMs) are initiated in 2022.***
- SAV nutrient sinks simulation. ***Response: This will be explicitly included in the MBM for the first time in a CBP tidal water simulation.***
- Living resources interactions. ***Response: This will be improved and refined from the previous Bay Model in both the MBM and MTMs.***
- A simulation option made available for finer scale assessment in the watershed and in the tidal Bay so that all watershed streams and the tidal tributaries and embayments can be simulated. ***Response: To sufficiently respond to this task the CBP will need to begin the Multiple Tributary Model work.***
- Improvements in shallow water modeling (estuarine model). ***Response: This will be included in MBM but would be made more robust and improved with the Multiple Tributary Models.***
- Simulating dynamics in shallow water. ***Response: Shallow water dynamics will be included somewhat in the MBM, but the scale will be finer and more appropriate for simulating shallow water dynamics with the Multiple Tributary Model.***
- Focus on shallow waters modeling in part because they introduce significant uncertainty that modeling could help flesh out a little bit more. Focus on shallow waters also readily engages stakeholders, including mobilization of resources. ***Response: Good recommendation and this is a specific task in the MBM and MTMs.***
- Need models that would allow the assessment of different water uses (for example cold water and small embayments) and to show progress at the scales where progress has been made. ***Response: The MTMs would be best suited to this task but the task might be data limited.***
- Focus on progress that can be made in shallow waters. ***Response: Fully agree and the MBM and MTMs will be the more capable in this task than any previous CBP model phase.***
- Improve simulation of temperature and DO in shallow open water. ***Response: This will be done in the MBM to some extent and is a task that will further developed and improved with the MTMs.***

Main Bay Model (MBM) and Multiple Tributary Models (MTMs) - Comments and Recommendations

- Improve resolution of grid to better estimate climate change effects. ***Response: This will be done in the MBM to some extent and is a task that will further developed and improved with the MTMs.***
- Improve seasonality of climatological parameters. ***Response: The response of the watershed and tidal Bay to the changes in loads brought about by CC with longer growing seasons, smaller spring freshets, etc. will be a focus of the Phase 7 WSM, MBM, and MTMs and is a task included in the MBM and MTM workplans.***
- Improve simulation of "problem tributaries". ***Response: This is an excellent recommendation and the task has been added to the MBM and MTM work plans.***
- Develop tributary specific sub-models. ***Response: This will be done in the Multiple Tributary Model workplan.***
- Improve wind driven dynamics. ***Response: This has been done in the last Bay Model version and was thoroughly documented in Wang, P., Wang, H. & Linker, L., 2015. Relative Importance of Nutrient Load and Wind on Regulating Interannual Summer Hypoxia in the Chesapeake Bay.*** **Estuaries and Coasts** ***38, 1048–1061 (2015). https://doi.org/10.1007/s12237-014-9867-5.***
- Add ability to model incremental progress, attainment in individual segments and uses. ***Response: The Phase 7 MBM and MTMs will allow a better assessment of incremental progress and water quality attainment in individual segments and uses than in any previous CBP model phases.***
- Improve nutrient speciation simulation. ***Response: This will be done in the Phase 7 MBM and MTMs and has been added to the workplan tasks. The nutrient speciation improvement will be done by better tracking the watershed-to-tidal Bay and the water column-to-sediment exchanges of the different nutrient species both between and within the Phase 7 Models.***
- Add ability for model to estimate WQ response based on different conditions. ***Response: To***
- Re-assess Sediment TMDL based on clarity. ***Response: This will be done in the Phase 7 Model application. Clarity/SAV is a key Chesapeake water quality standard and the MBM and MTMs will give us the scale needed to better assess SAV than in any previous CBP model phase.***
- Wait on MTMs. ***Response: The comment is acknowledged along with twelve responses in favor of developing the MTMs or key aspects of the MTMs and two comments suggesting a pause on MTM development.***

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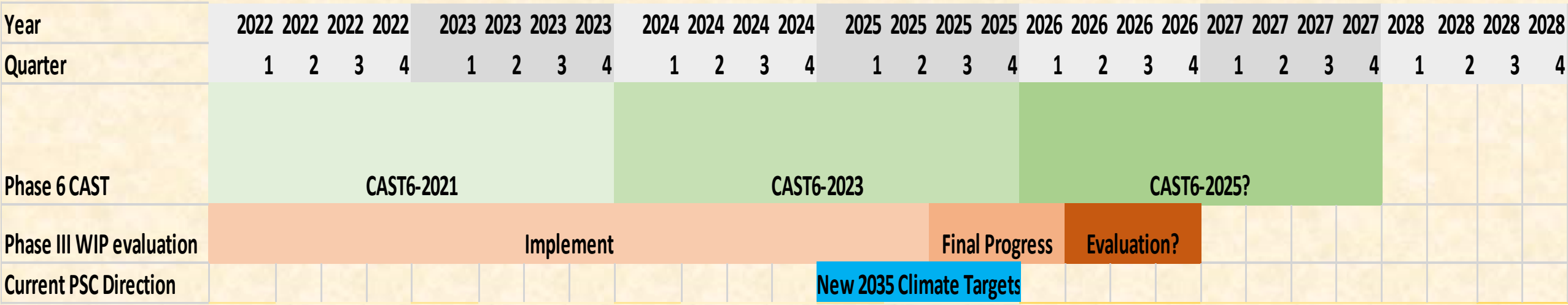
Current Phase III WIP, 2025 Assessment and 2035 Climate Targets Schedule



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Proposed Phase III WIP, 2025 Assessment and 2035 Climate Targets Schedule

Year	2022	2022	2022	2022	2023	2023	2023	2023	2024	2024	2024	2024	2025	2025	2025	2025	2026	2026	2026	2026	2027	2027	2027	2027	2028	2028	2028	2028
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Phase 6 CAST	CAST6-2021								CAST6-2023								CAST6-2025?											
Phase III WIP evaluation	Implement															Final Progress	Evaluation?											
Under Discussion																					New 2035 Climate Targets, combine with new model and Conowingo							

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Overview of the Main Bay Model (MBM) Workplan: Initial Development Phase

Task 1. Initial Development (2022 – 2023)

1-1. Kick-off MBM meeting with follow-up CBPO Quarterly meetings to decide tasks to be completed, priority model activities and improvements, and finalize the schedule for progress reporting (Q1-Q2: 2022).

1-2. Integrate the latest ICM changes into MBM (Q1-Q2: 2022).

1-3. Revise the current MBM mesh to achieve best scale and performance tradeoffs (Q1-Q2: 2022).

1-4. Revise MBM mesh to account for channels in MBM and MTMs (Q1-Q2: 2022).

1-5. Performance tuning of MBM to achieve 1991-2000 simulation in one day (Q1-Q3: 2022).

1-6. Work with watershed, airshed, hydrological modeling groups to ensure the coupling, scale, and the interface mechanisms are properly executed, including climate change (CC) input information (All Qs: 2022-2023).

1-7. Develop boundaries of MBM, WSM, and tidal wetlands (Q1: 2022).

1-8. Quantify how boundaries of MBM, WSM, and tidal wetlands will change with SLR (Q2: 2022).

1-9. Develop SAV simulation approach of explicit beds or bounded seed in every mesh (All Qs: 2022-2023).

1-10. Establish MBM-MTM boundary interfaces for all MTMs (All Qs:2022).

1-11. Develop MTM grids in anticipation of MTM teams (All Qs: 2022).

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Overview of the Main Bay Model (MBM) Workplan: Initial Development Phase *(cont.)*

Task 1. Initial Development (2022 – 2023)

1-12. CBP decision makers to finalize 5 MTMs (Q2-Q3: 2022).

1-13. Link with initial P7 WSM hydrology (4Q: 2022).

1-14. Link with initial P7 WSM sediment load estimates (1Q: 2023).

1-15. Link with initial P7 WSM nutrient load estimates (3Q: 2023).

1-16. Expand temporal domain of MBM to focus on 1991-200, 1993-1995, recent years for good calibration data, and the full 1985-present for coastal eutrophication research (All Qs: 2022-2023).

1-17. Initial work to improve shallow water dynamics in MBM (All Qs: 2022-2023).

1-18. Initial work to improve shallow water dynamics in MTMs (All Qs: 2023).

1-18. Initial work on basic living resource linkages of refined chlorophyll, wetlands, & SAV MBM & MTM (All Qs: 2022).

1-19. Initial work on potential linkage to higher trophic levels MBM & MTMs (All Qs: 2023).

1-20. Initial work of using MBM and MTMs to better resolve CBP problem segments (All Qs: 2023).

1-21. Initial work on examining climate change influence on SAV, shallow water, and phenology of CC watershed loads and tidal Bay processing MBM & MTM (All Qs: 2023).

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Overview of the Main Bay Model (MBM) & Multiple Tributary Model (MTM) Workplan: Initial Development Phase

Calendar Year		2022				2023				2024			
Calendar Quarter		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project Year		Year 1				Year 2				Year 3			
Task 1. Initial MBM-MTM Development (2022 – 2023)	Task 1												
1-1. Kick-off MBM meeting, with follow-up CBPO Quarterly meetings (Q1-Q2: 2022).	Task 1.1												
1-2. Integrate the latest ICM changes into MBM (Q1-Q2: 2022).	Task 1.2												
1-3. Revise the current MBM mesh as needed to achieve best scale-performance tradeoffs (Q1-Q3: 2022).	Task 1.3												
1-4. Revise MBM mesh to account for channels in MBM and MTMs (Q1-Q2: 2022)	Task 1.4												
1-5. Performance tuning of MBM to achieve 1991-2000 simulation in one day (Q1-Q3: 2022).	Task 1.5												
1-6. Work with watershed, airshed, hydrological modeling group's inputs (All Qs: 2022-2023).	Task 1.6												
1-7. Develop boundaries of MBM, WSM, and tidal wetlands (Q1: 2022).	Task 1.7												
1-8. Quantify how boundaries of MBM, WSM, and tidal wetlands will change with SLR (Q2: 2022).	Task 1.8												
1-9. Develop SAV simulation approach: explicit beds or bounded seed in every mesh (All Qs: 2023).	Task 1.9												
1-10. Establish MBM-MTM boundary interfaces for all MTMs (All Qs:2022).	Task 1.10												
1-11. Develop MTM grids in anticipation of MTM teams (All Qs: 2022).	Task 1.11												
1-12. CBP decision makers to finalize 5 MTMs (Q2-Q3: 2022).	Task 1.12												
1-13. Link with initial P7 WSM hydrology (Q4: 2022, Q1: 2023).	Task 1.13												
1-14. Link with initial P7 WSM sediment load estimates (1Q-Q2: 2023).	Task 1.14												
1-15. Link with initial P7 WSM nutrient load estimates (3Q-Q4: 2023).	Task 1.15												
1-16. Expand temporal domain of MBM to focus on 1991-200 and other key years (All Qs: 2022-2023).	Task 1.16												
1-17. Initial work to improve shallow water dynamics in MBM (All Qs: 2022-2023).	Task 1.17												
1-18. Initial work to improve shallow water dynamics in MTMs (All Qs: 2023).	Task 1.18												
1-18. Initial work on basic living resource linkages of refined chlorophyll, wetlands, & SAV (All Qs: 2022-2023)	Task 1.19												
1-19. Initial work on potential linkage to higher trophic levels MBM & MTMs (All Qs: 2023).	Task 1.20												
1-20. Initial work of using MBM and MTMs to better resolve CBP problem segments (All Qs: 2023).	Task 1.21												
1-21. Initial work on examining CC influence on phenology MBM & MTM (All Qs: 2023).	Task 1.22												

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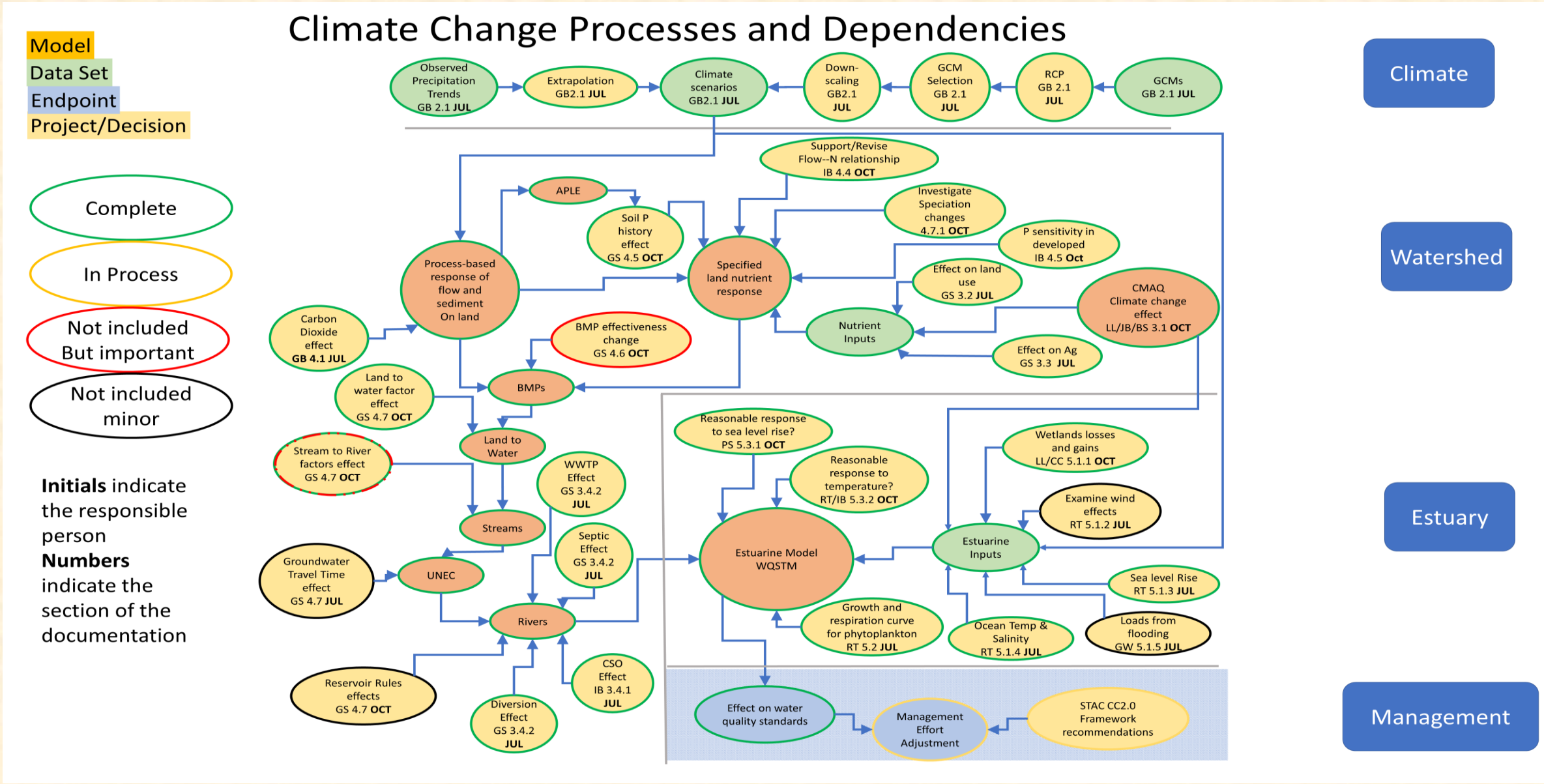
Elements of Chesapeake Water Quality 2035 CC Assessment



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Overview of the Main Bay Model (MBM) Workplan: Interim Development Phase (2023-2024)

Task 2 Interim MBM and MTM Development (2023 – 2024)

2-1. Initiate MTM activities (Q1-Q2: 2023).

2-2. Kick-off joint meetings of MBM and MTM Teams with Mod WG (Q1-Q2: 2023)

2-3. Conduct full initial calibration and verification of hydrodynamic and WQ model output (Q3-Q4: 2024).

2-4. Address important knowledge gaps in ICM (All Qs: 2024).

2-5. Begin completion of work to improve shallow water dynamics in MBM (All Qs: 2024).

2-6. Begin completion of work to improve shallow water dynamics in MTMs (All Qs: 2024).

2-7. Completion of work on basic living resource linkages of refined chlorophyll, wetland, and SAV simulation and potential linkage to higher trophic levels (All Qs: 2024).

2-8. Completion of work using MBM and MTMs to better resolve CBP problem segments (All Qs: 2024).

2-9. Completion of work examining CC influence on SAV, shallow water, & phenology of CC watershed loads and tidal Bay processing (All Qs: 2024).

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Overview of the Main Bay Model (MBM) and Multiple Tributary Model (MTM) Workplan: Interim Development Phase (2023-2024)

Calendar Year		2023				2024				2025			
Calendar Quarter		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project Year		Year 2				Year 3				Year 4			
Task 2 Interim MBM and MTM Development (2023 – 2024)	Task 2												
2-1. Initiate MTM activities (Q1-Q2: 2023).	Task 2.1												
2-2. Kick-off joint meetings of MBM and MTM Teams with Mod WG (Q1-Q2: 2023)	Task 2.2												
2-3. Conduct full initial calibration and verification of hydrodynamic and WQ model output (Q3-Q4: 2024).	Task 2.3												
2-4. Address important knowledge gaps in ICM (All Qs: 2024).	Task 2.4												
2-5. Begin completion of work to improve shallow water dynamics in MBM (All Qs: 2024).	Task 2.5												
2-6. Begin completion of work to improve shallow water dynamics in MTMs (All Qs: 2024).	Task 2.6												
2-7. Completion of work on basic living resource linkages of refined chlorophyll, wetland, and SAV simulation an	Task 2.7												
2-8. Completion of work using MBM and MTMs to better resolve CBP problem segments (All Qs: 2024).	Task 2.8												
2-9. Completion of work examining CC influence on SAV, shallow water, & phenology of CC watershed loads and	Task 2.9												
Task 3 Final MBM and MTM Development (2005)	Task 3												
3-1. Provide a fully operational MBM that meets the needs of CBP (Q2-Q3: 2025).	Task 3.1												
3-2. Finish documentation on the software package in a report that will include detailed documentation on model st	Task 3.2												
3-3. Demonstrate feasibility and utility of using a state of the science UG model to better estimate Chesapeake WQ	Task 3.3												
3-4. Transfer the software package to CBPO for operational testing, and work with CBPO personnel to test the mo	Task 3.4												
3-5. All MBM and MTMs fully operational (Q4: 2025).	Task 3.5												

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Overview of the MBM and MTM Workplan: Final Model Development (2025)

Task 3 Final MBM and MTM Development (2025)

3-1. Provide a fully operational MBM that meets the needs of CBP (Q2-Q3: 2025).
3-2. Finish documentation on the software package in a report that will include detailed documentation on model structure, major code changes, validation and calibration procedure and usage (Q4: 2025).
3-3. Demonstrate feasibility and utility of using a state of the science UG model to better estimate Chesapeake WQ standards in shallow open waters under 2035 and future climate change conditions (All Qs: 2025).
3-4. Transfer the software package to CBPO for operational testing, and work with CBPO personnel to test the model package under operational settings and resolve any issues that may arise (Q3-Q4: 2025).
3-5. All MBM and MTMs fully operational (Q4: 2025).
3-6. Conduct full review of al MBM and MTMs with CBP technical and management groups and with STAC (All Qs: 2026).
3-7. Review all recent studies related to Bay WQ processes and work with CBP and Mod-WG to identify key missing processes and update the code to address knowledge gaps as they are filled (All Qs: 2025).
3-8. Provide estuarine models, analysis tools, and initial scoping scenarios, final code version and other materials to CBPO for testing (Q3-Q4: 2025).
3-9. Finalize work to improve shallow water dynamics in MBM (Q1-Q2: 2025).
3-10. Finalize work to improve shallow water dynamics in MTMs (Q1-Q2: 2025).
3-11. Finalize work on basic living resource linkages of refined chlorophyll, wetland, and SAV simulation and potential linkage to higher trophic levels (All Qs: 2025).
3-12. Finalize work using MBM and MTMs to better resolve CBP problem segments (Q1-Q2: 2025).
3-13. Finalize work examining CC influence on SAV, shallow water, and phenology of CC watershed loads and tidal Bay processing (Q1-Q2: 2025).

Overview of the MBM & MTM: Final Model Development (2025)

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		2025			
Calendar Year					
Calendar Quarter		Q1	Q2	Q3	Q4
Project Year		Year 4			
Task 3 Final MBM and MTM Development (2005)	Task 3				
3-1. Provide a fully operational MBM that meets the needs of CBP (Q2-Q3: 2025).	Task 3.1				
3-2. Finish documentation on the software package in a report that will include detailed documentation on model st	Task 3.2				
3-3. Demonstrate feasibility and utility of using a state of the science UG model to better estimate Chesapeake WQ	Task 3.3				
3-4. Transfer the software package to CBPO for operational testing, and work with CBPO personnel to test the mo	Task 3.4				
3-5. All MBM and MTMs fully operational (Q4: 2025).	Task 3.5				
3-6. Conduct full review of al MBM and MTMs with CBP technical and management groups and with STAC (All	Task 3.6				
3-7. Review all recent studies related to Bay WQ processes and work with CBP and Mod-WG to identify key miss	Task 3.7				
3-8. Provide estuarine models, analysis tools, and initial scoping scenarios, final code version and other materials	Task 3.8				
3-9. Finalize work to improve shallow water dynamics in MBM (Q1-Q2: 2025).	Task 3.9				
3-10. Finalize work to improve shallow water dynamics in MTMs (Q1-Q2: 2025).	Task 3.10				
3-11. Finalize work on basic living resource linkages of refined chlorophyll, wetland, and SAV simulation and pot	Task 3.11				
3-12. Finalize work using MBM and MTMs to better resolve CBP problem segments (Q1-Q2: 2025).	Task 3.12				
3-13. Finalize work examining CC influence on SAV, shallow water, and phenology of CC watershed loads and tic	Task 3.13				

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MBM and MTM Review (2026) and Application (2027)

Task 4. MBM and MTM Review (2026) and Application (2027)

4-1. Provide final estuarine models, analysis tools, model documentation and other materials to CBPO (Q1:2026).

4-2. Improve the CBP management decisions through the successful application of developing quantitative assessments of climate change in the Chesapeake main-Bay and in ultra-local tidal waters, as directed by CBP managers with detailed estimates for how to respond to 2035 climate change challenge (All Qs: 2027).

4-3. Provide initial (2026) and final (2027) scoping scenarios, analyses, and other materials to support Chesapeake protection and restoration efforts and address the needs and requirements of CBP decision makers and managers for responding to climate change in the Chesapeake (All Qs: 2026 & 2027).

4-4. Develop user-friendly interfaces with model software and technical transfer training so that a variety of stakeholders can have full access and know how to use to pre- and post-processing, visualization, and scenario tools (All Qs: 2026).

4-5. Develop and apply 2035 CC and all other management MBM and MTM scenarios as determined by CBP decision makers (Q3, Q4: 2026 & all Qs; 2027).

4-6. Document the findings and recommendations in the final report (Yr 6: 2027).

4-7. Provide final TMDL scenario simulation results to address the needs and requirements of CBP decision makers and managers for responding to climate change in the Chesapeake, tributaries, and in ultra-local areas as requested. (Q3, Q4: 2027).

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MBM and MTM Review (2026) and Application (2027)

		2026				2027			
Calendar Year									
Calendar Quarter		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project Year		Year 5				Year 6			
Task 4. MBM and MTM Review (2026) and Application (2027)									
4-1. Provide final estuarine models, analysis tools, model documentation and other materials to CBPO (Q1:2026).									
4-2. Improve the CBP management decisions through the successful application of developing quantitative assessments c									
4-3. Provide initial (2026) and final (2027) scoping scenarios, analyses, and other materials to support Chesapeake prot									
4-4. Develop user-friendly interfaces with model software and technical transfer training so that a variety of stakeholder									
4-5. Develop and apply 2035 CC and all other management MBM and MTM scenarios as determined by CBP decision r									
4-6. Document the findings and recommendations in the final report (Yr 6: 2027).									
4-7. Provide final TMDL scenario simulation results to address the needs and requirements of CBP decision makers and									

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MBM and MTM Continuous Activities (2022 - 2027)

Task 5. Continuous Activities

5-1. Support the Modeling Workgroup, WQGIT, and other technical and management/policy CBP groups as needed (All Qs: 2022-2027).

5-2. Host a dedicated web site for the new Main Bay Model (MBM) (All Qs: 2022 2027 with final deliverable Q3 2027).

5-3. Submit annual reports with detailed documentation on model structure, major code changes, validation, and calibration procedure and usage (Q4 each year: 2022-2027).

5-4. Disseminate research findings & experiences via 1-2 journal papers/year (All Qs: 2022-2027).

5-5. Coordination/collaboration meetings among MBM and MTM Teams (All Qs: 2023-2027 coincident with CBP Modeling Quarterlies).

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MBM and MTM Continuous Activities (2022 - 2027)

		2026				2027			
Calendar Year									
Calendar Quarter		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project Year		Year 5				Year 6			
Task 5. Continuous Activities	Task 5								
5-1. Support the Modeling Workgroup, WQGIT, and other technical and management/policy CBP groups as needed (All	Task 5.1								
5-2. Host a dedicated web site for the new Main Bay Model (MBM) (All Qs: 2022 2027 with final deliverable Q3 202	Task 5.2								
5-3. Submit annual reports with detailed documentation on model structure, major code changes, validation, and calibrat	Task 5.3								
5-4. Disseminate research findings & experiences via 1-2 journal papers/year (All Qs: 2022-2027).	Task 5.4								
5-5. Coordination/collaboration meetings among MBM and MTM Teams (All Qs: 2023-2027 coincident with CBP Mod	Task 5.5								

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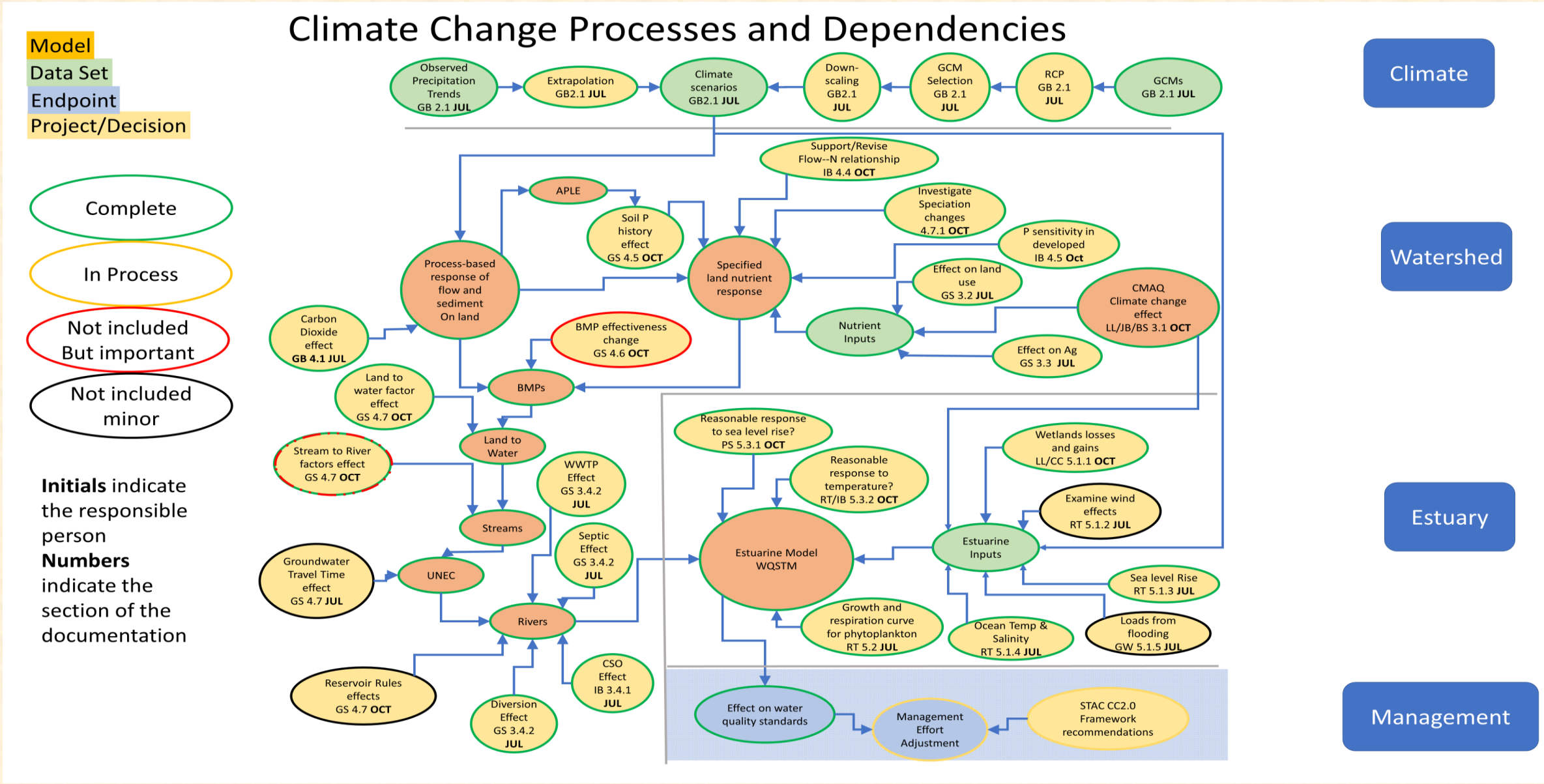
Elements of Chesapeake Water Quality 2035 CC Assessment



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Main Bay Model (MBM) Outcomes

1. Reduced nitrogen, phosphorus, and sediment delivered to tidal Bay waters appropriate to respond to 2035 and future climate change in order to achieve Bay water quality standards via an ultra-local modeling tool.

2. Amount of habitat restored as represented by achievement of the Chesapeake living-resource-based water quality standards and direct simulation, e.g., oysters or linkages to higher trophic levels, e.g., finfish.

3. Increased knowledge and strategies to improve local economic, human health, and environmental goals through a restored Chesapeake Bay; improved knowledge about the critical load of nutrients that the Chesapeake Bay would have under 2035 and future climate change via ensemble simulations CC and MBM-MTM).

4. Improved CBP decision making and leadership in responding to future climate change conditions through a flexible MBM-MTM modeling framework

5. Providing improved community model and analysis tools to serve both scientific community and stakeholders by supporting a large user community (many eyes).

6. Training of next-generation scientists including graduate students in Bay ecology, hydrodynamics, and biogeochemistry toward increasing scientific capacity for environmental problem solving in the region, by leveraging the education capacity in PIs' home institutes (many hands).