2016 Economic Studies

Preliminary high order of magnitude transmission development costs

Rev. 1

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SYSTEM PLANNING

Background

- Discussions concerning the 2016 NEPOOL Economic Study request are ongoing
  - Monthly PAC presentations have been made since April 2016 to review scope of work, assumptions, metrics and study results
- During these discussions, the ISO committed to developing high level order of magnitude cost estimates for the transmission needed to integrate renewable resources during on-peak load periods
  - This work is being done as part of Phase 1 of the study
- The ISO has identified potential transmission planning issues that will need to be addressed for the development of large-scale inverter based resources, including operational issues presented by off-peak load periods
  - More details regarding these operational issues are included in the presentation from the Electric Power Research Institute, available at https://www.iso-ne.com/static-assets/documents/2016/10/a3_integration_and_planning_of_large_amounts_of_inverter_based_resources.pptx

Purpose of Today's Presentation

- Review transmission flow results from the 2016 economic studies
  - Those were included in the September PAC presentation but not discussed at that time
- Present preliminary <u>high order of magnitude</u> transmission development costs to integrate renewable resources in New England
  - These cost estimates are very preliminary and based on judgement
    - They include costs that would be incurred beyond individual plant interconnection costs
  - They do not fully account for operational issues caused by the development of large-scale inverter based resources during off-peak load periods
  - This presentation focuses on the cost of integrating the <u>Maine</u> renewable resources
    - Based on the results of the economic study, renewable resources outside of northern and western Maine do not seem to cause a need for large scale transmission expansion
  - This <u>cost analysis</u> does not develop transmission expansion plans

TRANSMISSION FLOW RESULTS

Executive Summary - September PAC Presentation

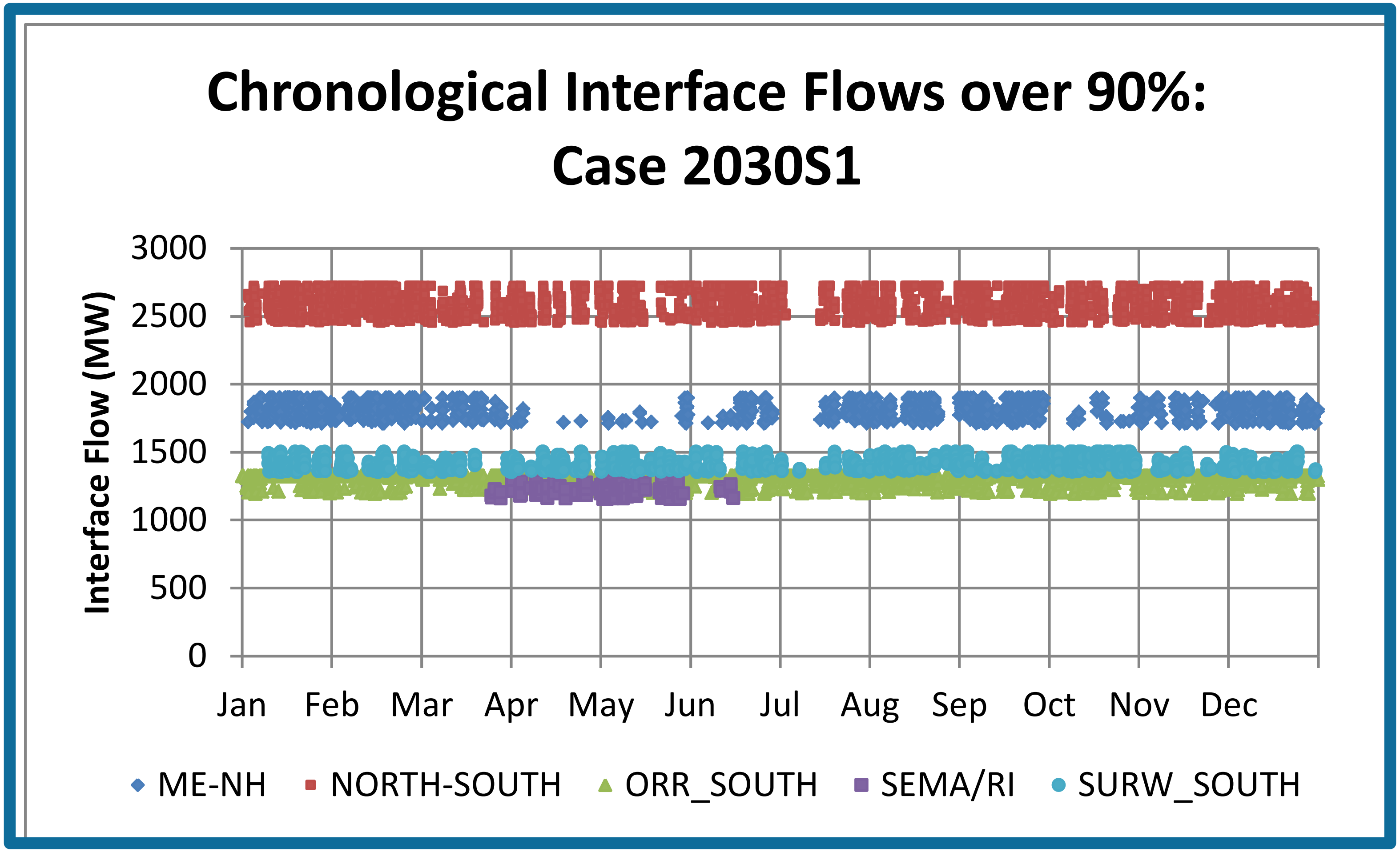
Summary: Transmission Flow Results

- Higher levels of wind resource additions in Northern New England result in a much greater use of the transmission system on the northern interfaces
  - The Orrington-South interface and the Surowiec-South interface become constrained more frequently
  - The northern interfaces see a larger daily variability in their flows, with the highest variability generally occurring in the summer months
    - Transfers are the highest in the early and late hours of the day; they are the lowest in the middle of the day
- Large additions of offshore wind in SEMA/RI cause flows on the SEMA/RI interface to reach greater magnitudes in both the import and export directions
- This large volatility in interface flows (larger range and daily variability) is not seen as much in Scenarios 4 and 5
  - Scenarios 4 and 5 have little congestion
  - This seems to imply that current resource locations are well integrated within the transmission system
  - The lack of intermittency of the resources in Scenarios 4 and 5 also contributes to limiting interface flow volatility

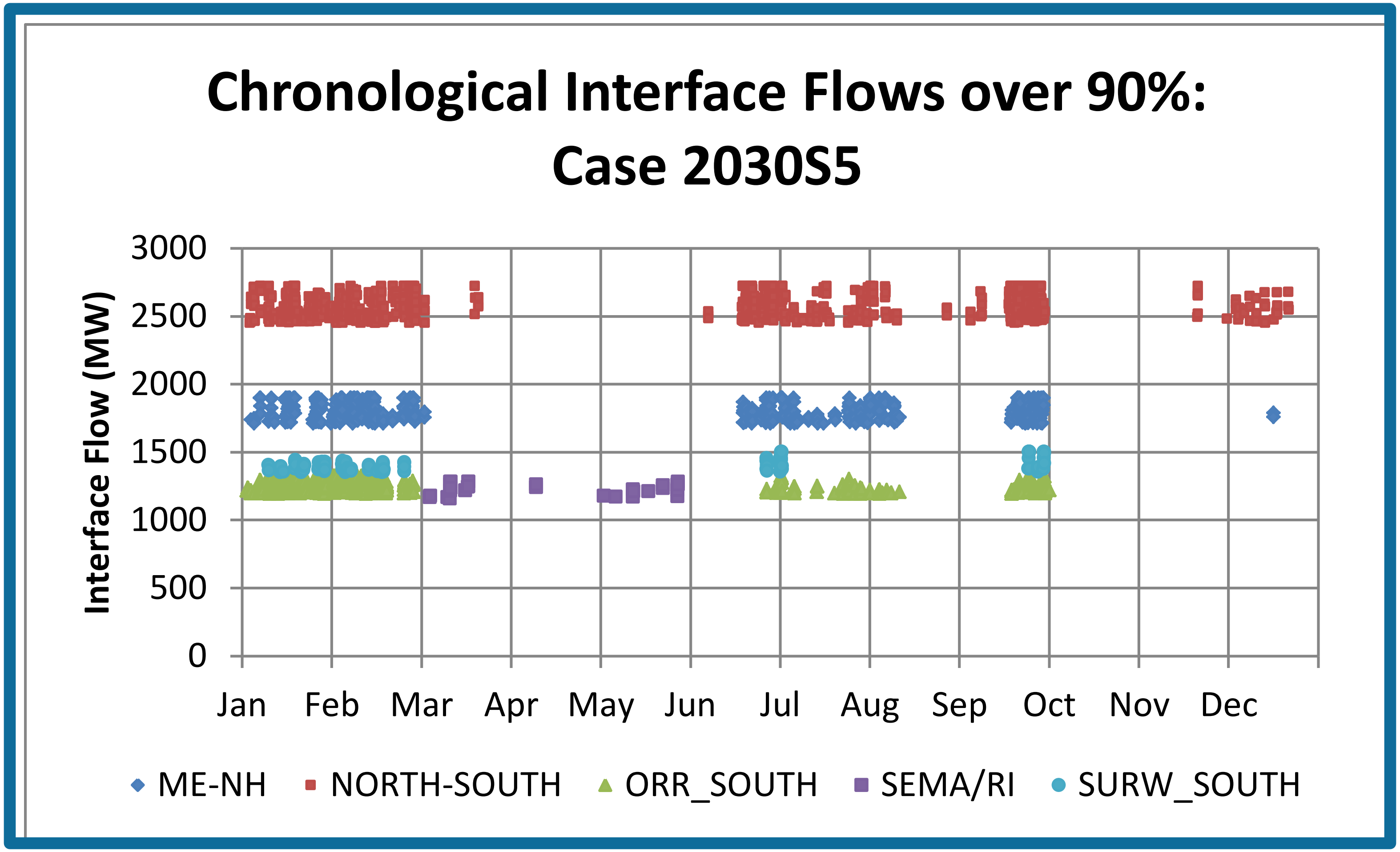
Observations From Chronological Interface Flows

- Chronological curves for interface flows that are above 90% of limit show the changes in the use of the transmission system between cases and over time
  - Scenarios 1, 2, and 3 generally show a higher amount of flows over 90% of limit
    - Higher levels of wind resource additions in Northern New England result in a much greater use of the transmission system on the northern interfaces
  - Scenario 5 shows the least amount of flows over 90% of limit
    - Current resource locations are relatively better integrated with the transmission system
  - Scenarios 4 and 5 show a reliance on the transmission system that is limited to the periods of higher loads (Summer and Winter seasons), while Scenarios 1, 2, and 3 show little seasonal difference
  - The above trends are accentuated more in the 2030 Scenarios than the 2025 Scenarios
    - A notable exception is the reduction in the use of the North-South interface in Scenario 3 in 2030 as compared with 2025
      - This is attributable partly to the higher amounts of EE, PV, and battery storage (smaller net load) and the higher amounts of off-shore wind in SEMA-RI
  - Scenario 3 shows a heavier reliance on the SEMA/RI import interface than all other cases

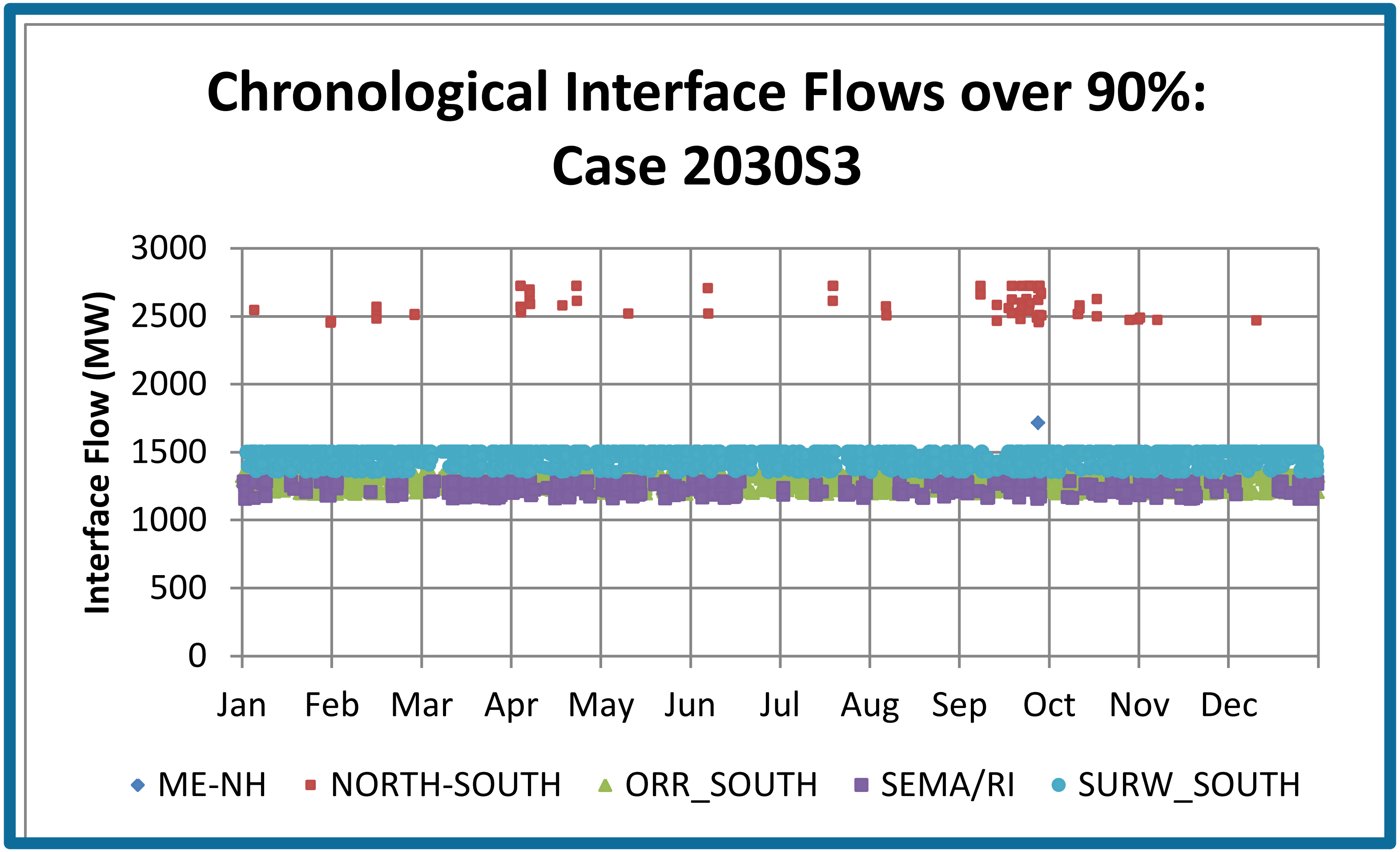
Chronological Interface Flows Exceeding 90% of Rating: 2030 Constrained Scenario 1



Chronological Interface Flows Exceeding 90% of Rating: 2030 Constrained Scenario 5



Chronological Interface Flows Exceeding 90% of Rating: 2030 Constrained Scenario 3

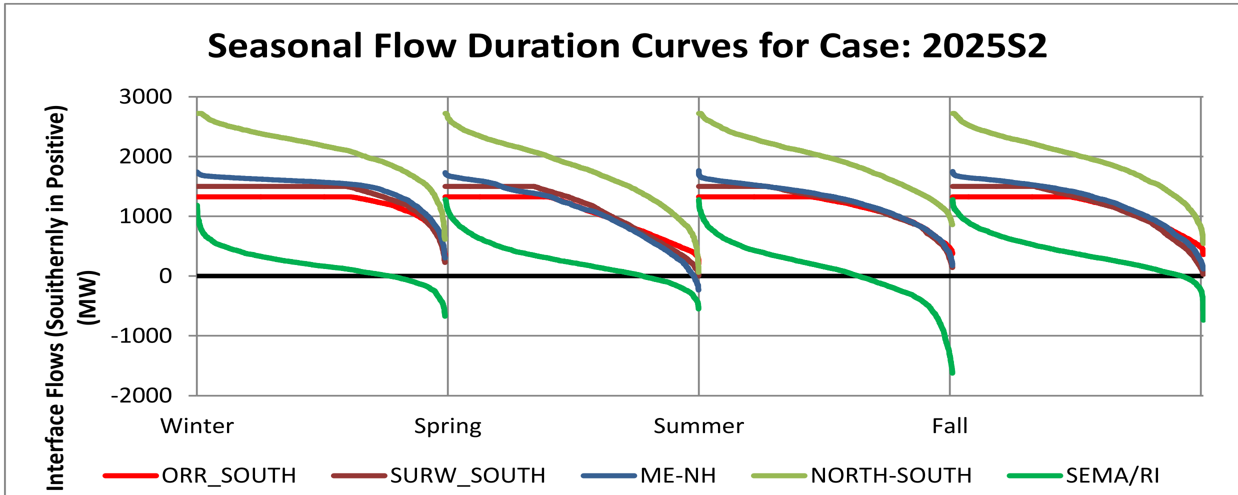


Observations From Seasonal Flow Duration Curves

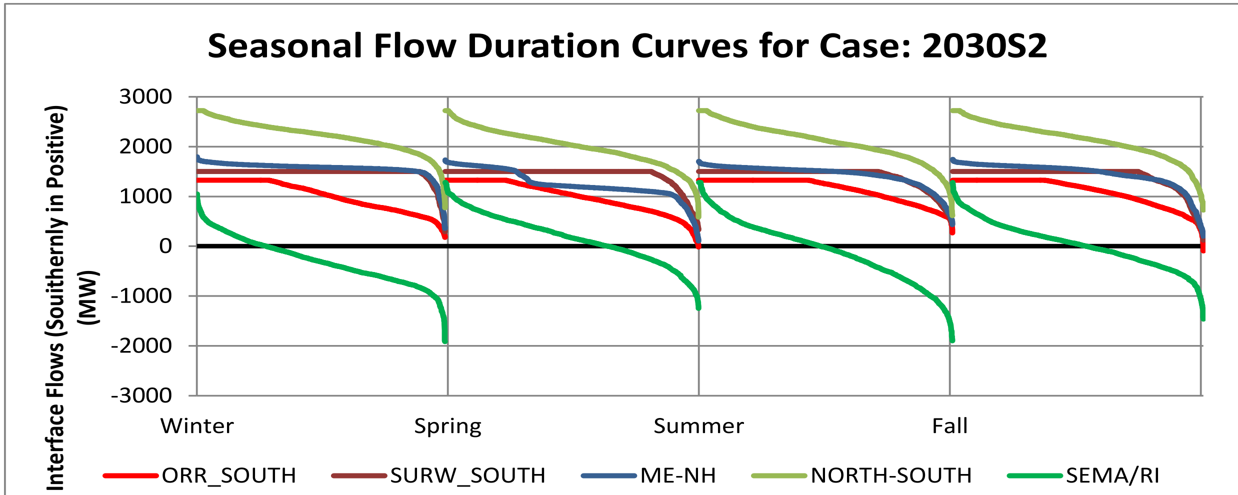
- Seasonal flow duration curves for interfaces provide additional intelligence on when and how interfaces become constrained
  - In Scenarios 1, 2 and 3, the Orrington-South interface is often constrained, due to the large addition of wind in the BHE area
    - The longer durations of constraints are seen in the Winter and Fall seasons, which are seasons with higher wind production
  - In Scenario 2, which has the highest addition of wind in Maine, south of the Orrington-South interface, the Surowiec-South interface also becomes significantly constrained
  - Scenarios 4 and 5 see very limited durations of constrained interfaces
  - In the year 2030, Scenario 3 shows the largest spread of flows on the SEMA/RI interface, with flows flowing both in the import and export directions a large portion of the time
    - Scenario 3 has the largest addition of SEMA/RI offshore wind among all cases
  - Unconstrained Scenarios show maximum amounts of flows on the interfaces, with flows reaching upward of 9,000 MW on the Orrington-South, Surowiec-South, Maine-New Hampshire and North-South interfaces in Scenario 2 for 2030
    - Scenario 2 has, by far, the highest amount of wind additions in Northern New England

Seasonal Flow Duration Curves – Constrained Scenario 2

2025

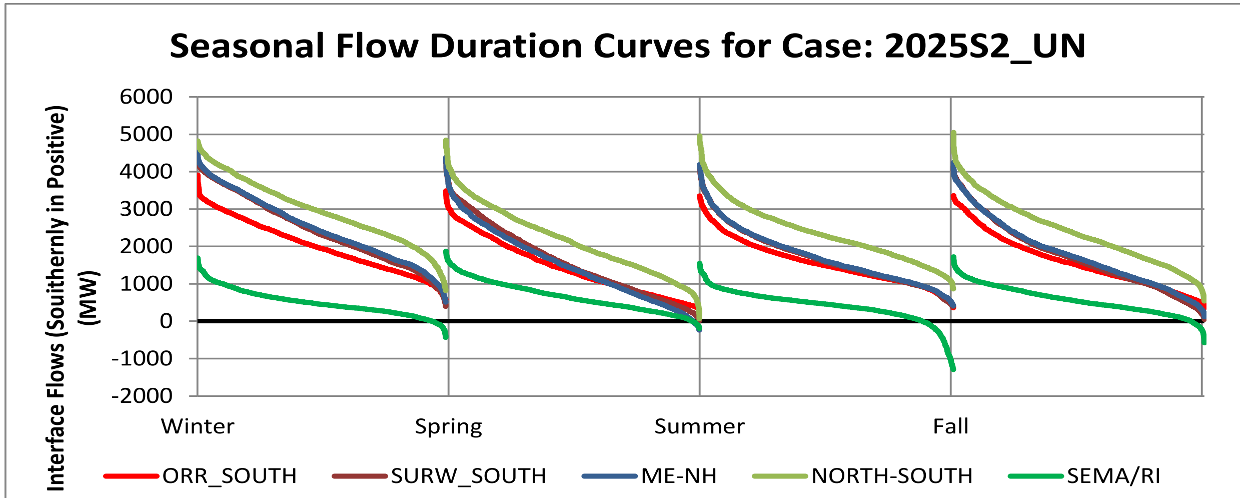


2030

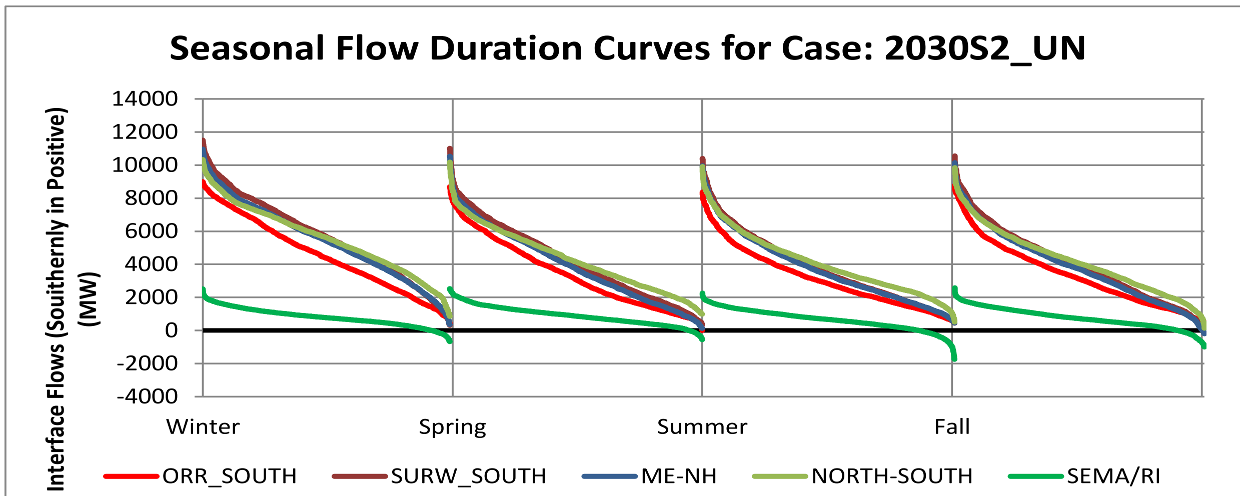


Seasonal Flow Duration Curves - Unconstrained Scenario 2

2025

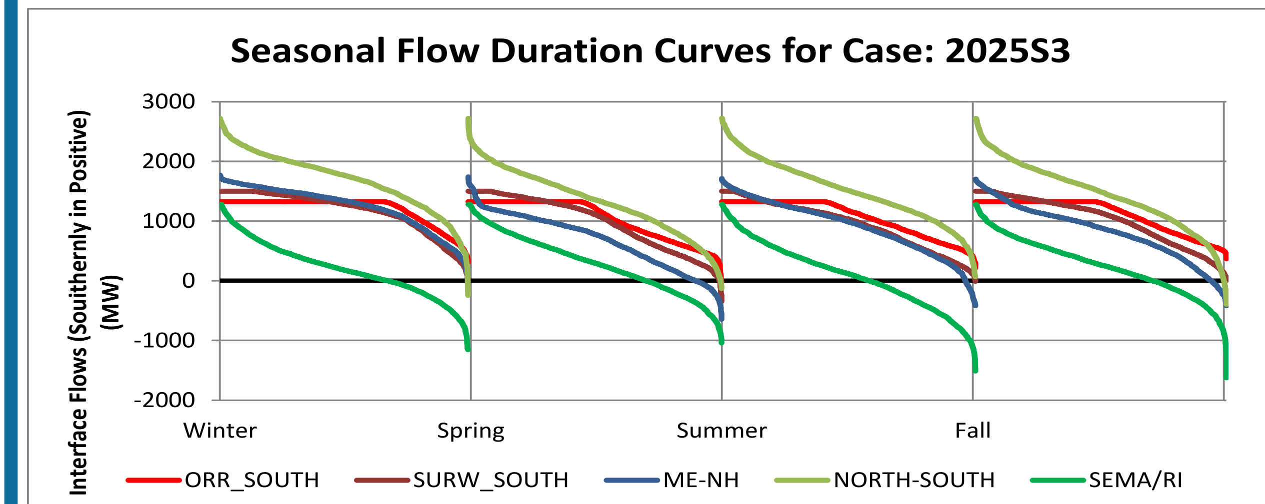


2030

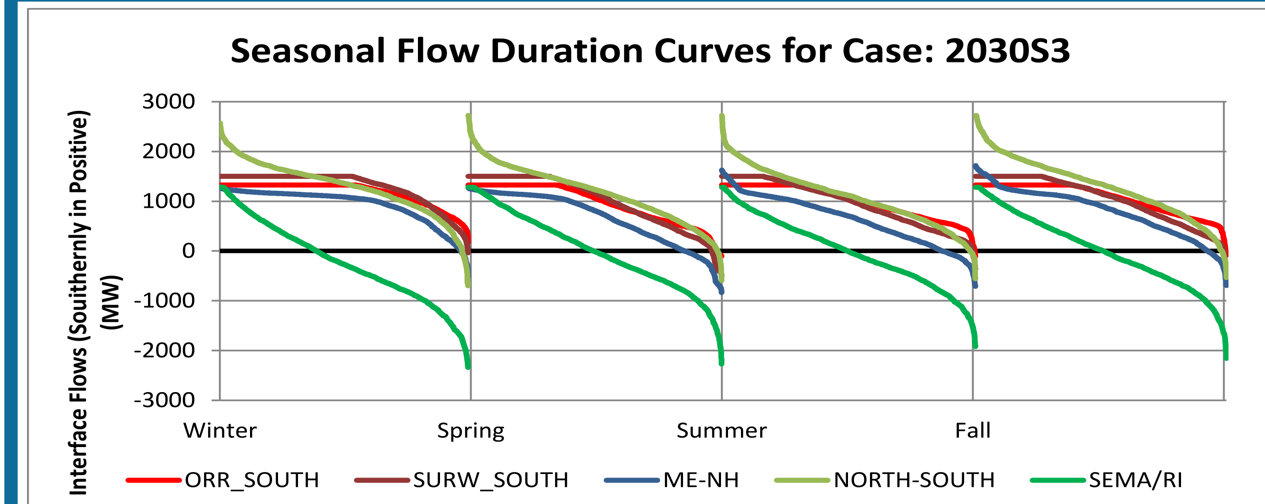


Seasonal Flow Duration Curves – Constrained Scenario 3

2025



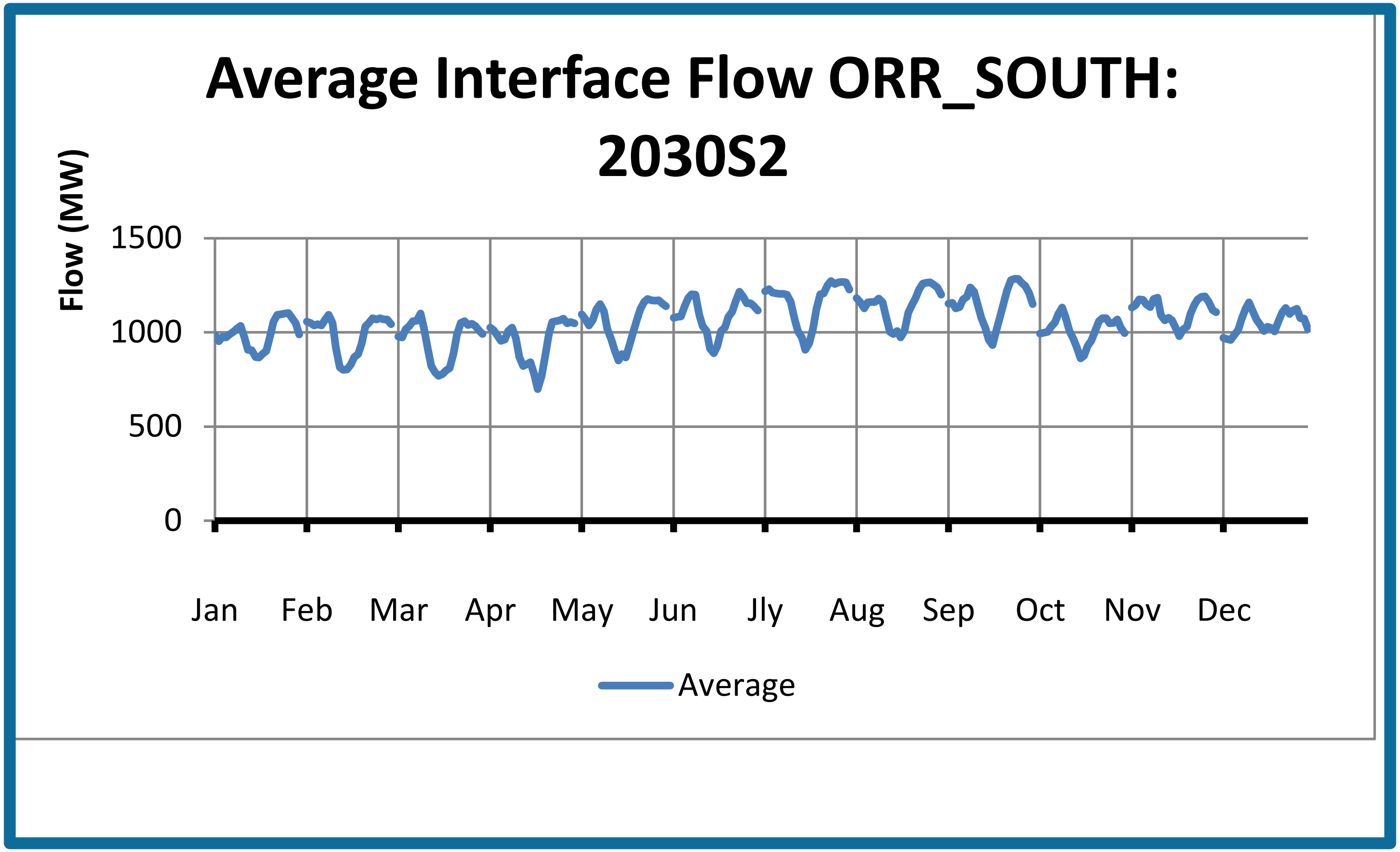
2030



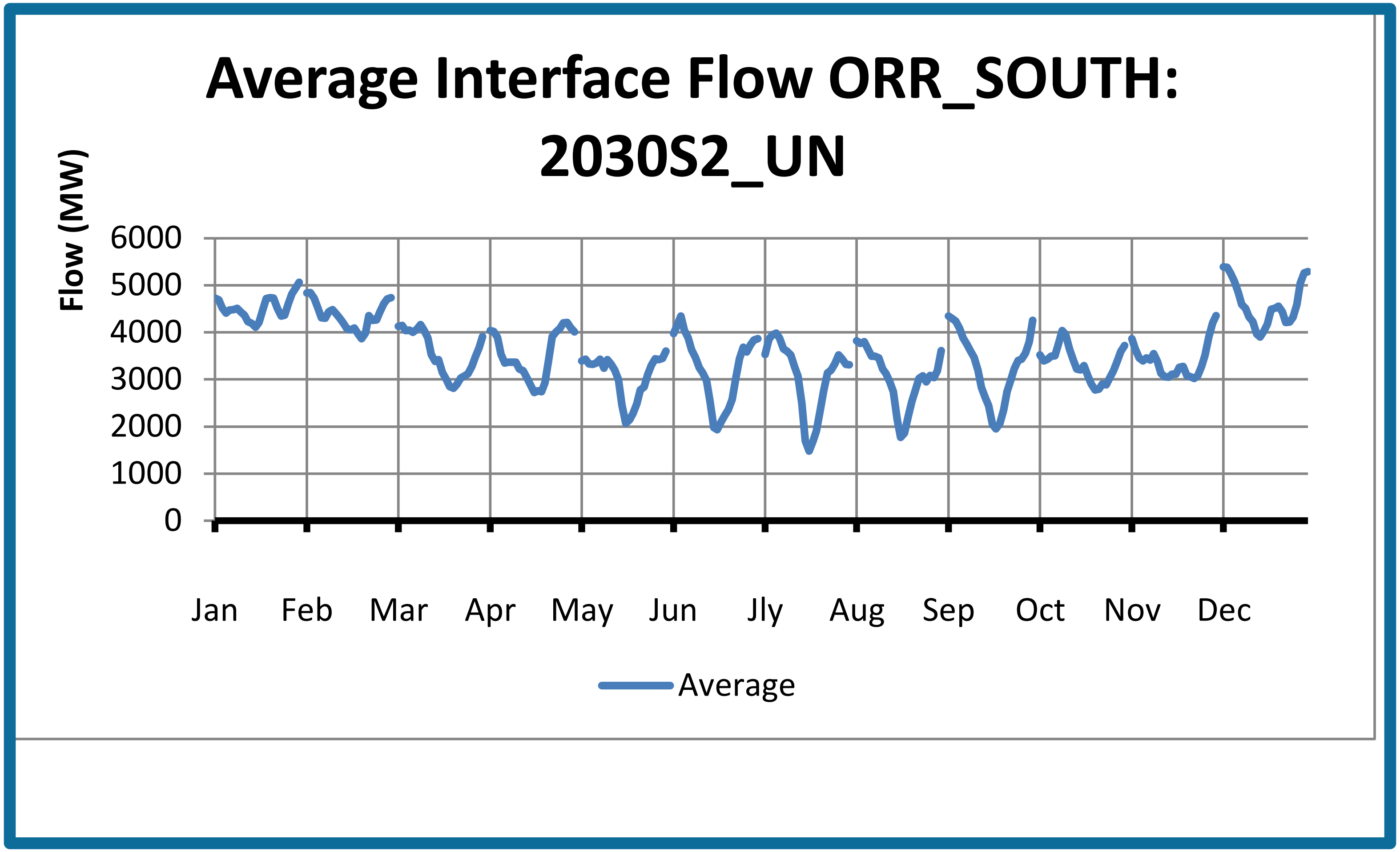
Observations From Diurnal Flows of Interfaces

- Average diurnal flows give a sense of the daily variability of the flows on each interface
  - In constrained Scenarios 1, 2 and 3, which have high wind production, there is a large daily variability of the flows over the interfaces
    - 300 to 500 MW on Orrington-South, 300 to 1,000 MW on Maine-New Hampshire, and 500 to 1,200 MW on North-South
  - In Scenarios 4 and 5, that have the lowest wind production, this variability is more limited
    - 200 MW on Orrington-South, 400 to 500 MW on Maine-New Hampshire, and 700 to 1,000 MW on North-South
  - In Scenarios 1, 2, and 3, the variability of the flows increases significantly with transmission constraints, whereas there is only a slight increase for Scenarios 4 and 5
    - The highest increase is seen for Scenario 2 in year 2030, where the average variability increases from 300 MW to 2,200 MW on the Orrington-South interface and 300 MW to 3,000 MW on the Maine-New Hampshire interface
  - In general, the highest daily variability occurs in the summer months
    - Transfers are the highest in the early and late hours of the day, and the lowest in the middle of the day

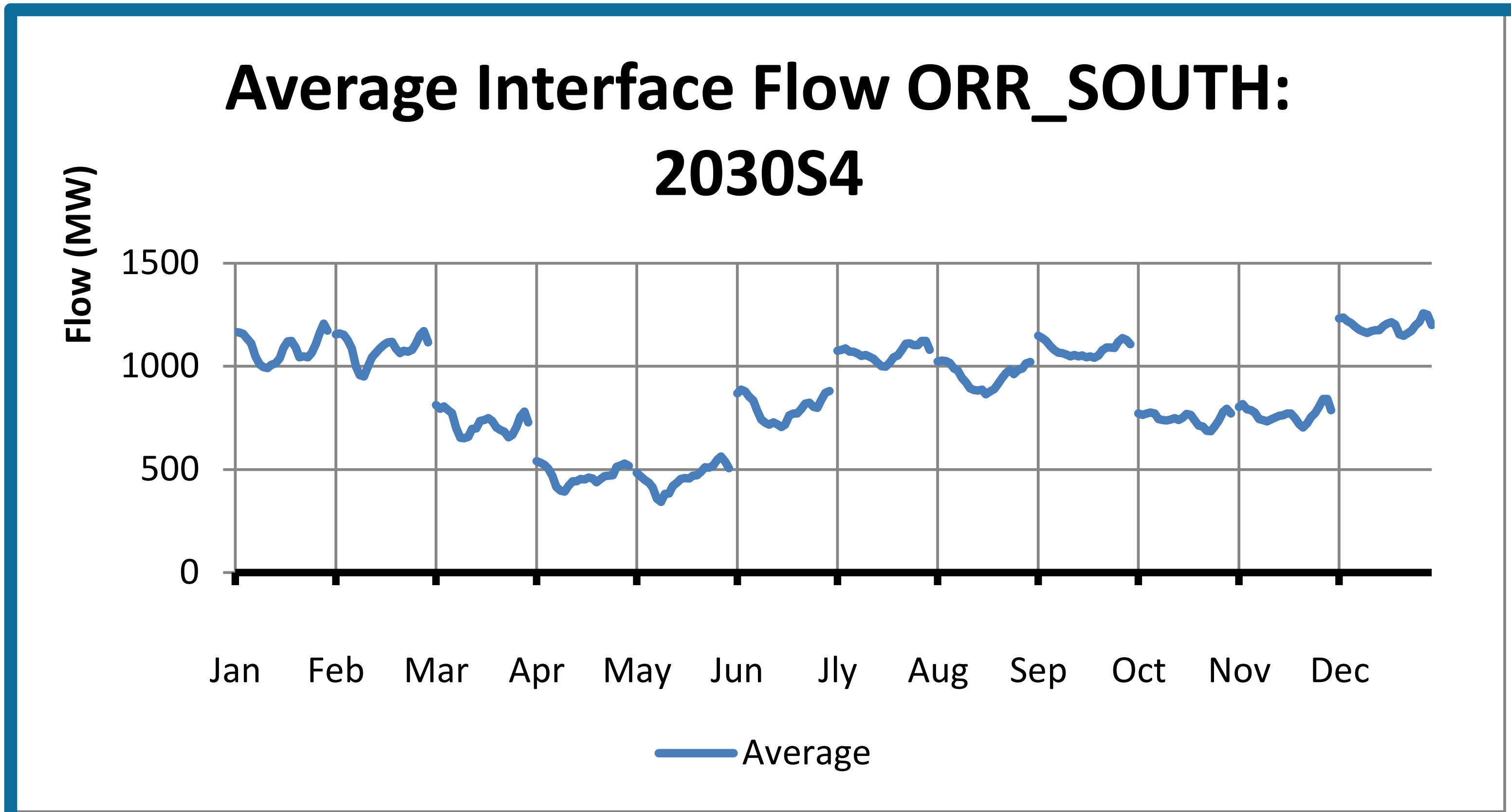
Diurnal Interface Flow: Orrington-South 2030 Constrained Scenario 2



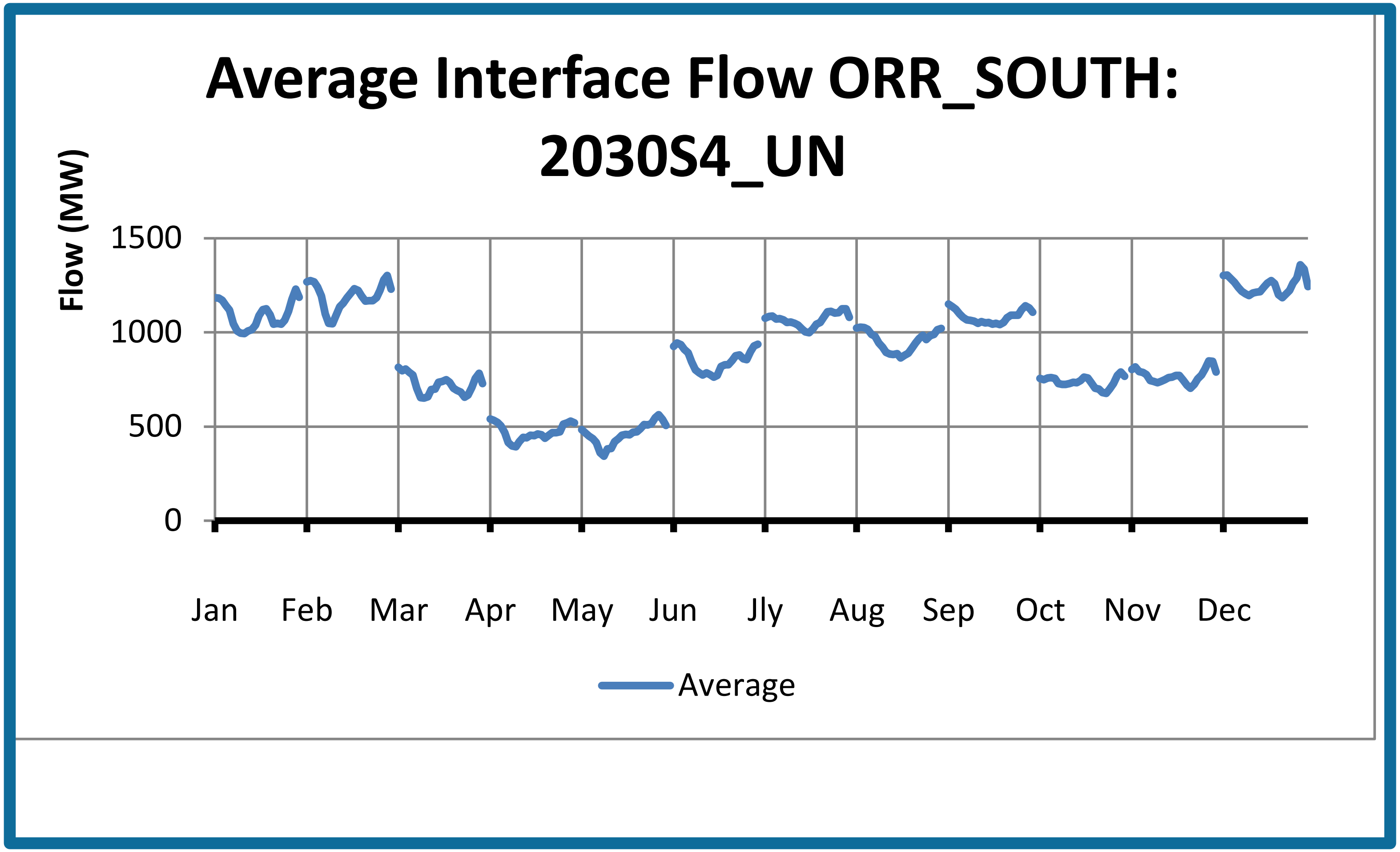
Diurnal Interface Flow: Orrington-South 2030 Unconstrained Scenario 2



Diurnal Interface Flow: Orrington-South 2030 Constrained Scenario 4



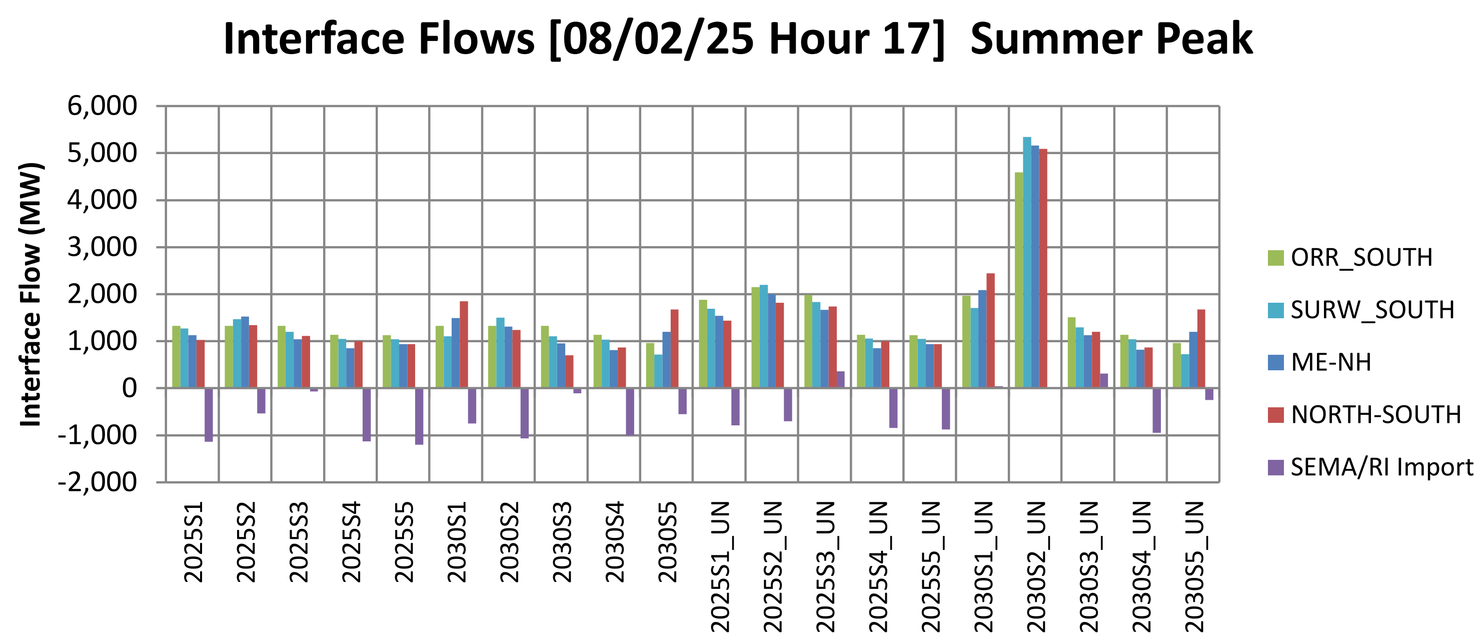
Diurnal Interface Flow: Orrington-South 2030 Unconstrained Scenario 4



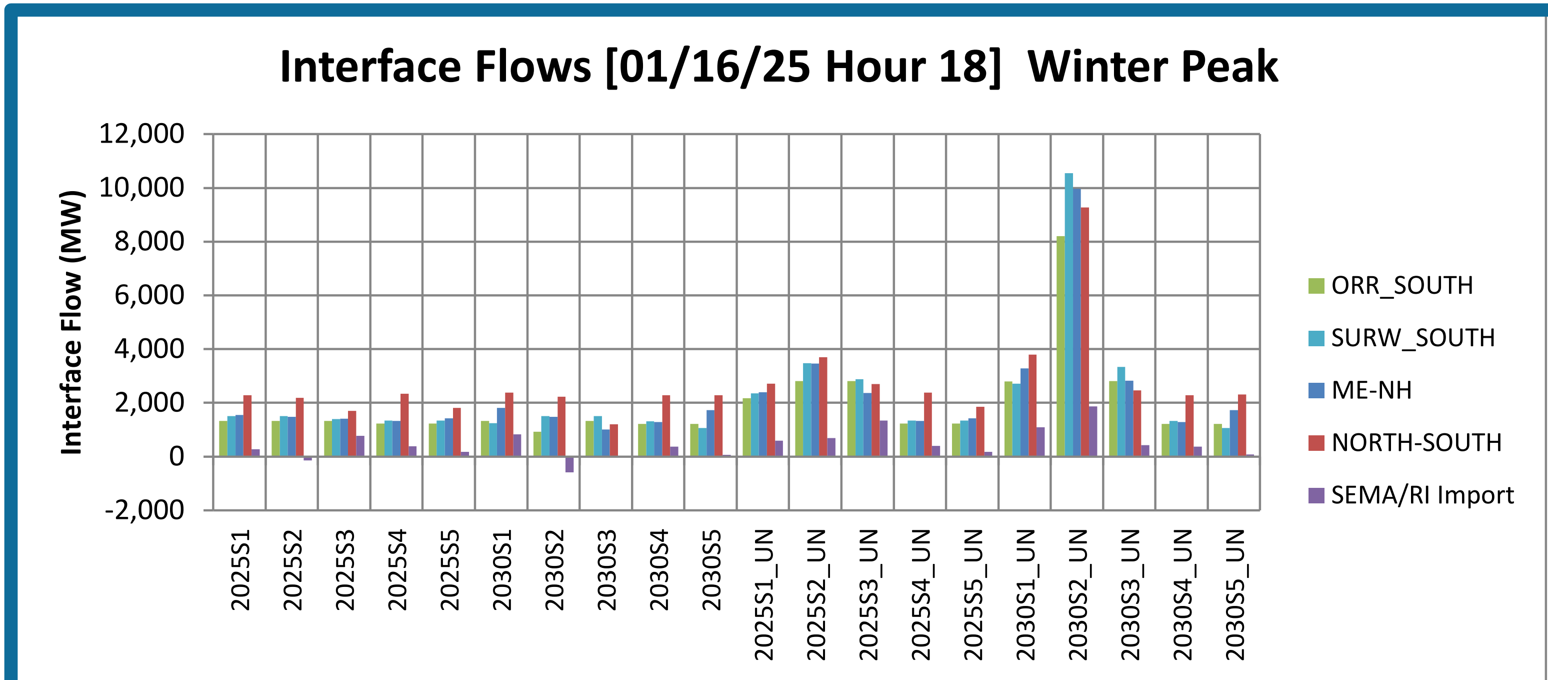
Observations From Interface Flows on Representative Summer and Winter Days

- Interface flows on representative summer and winter days, show the simultaneity of the flows across the various interfaces, in a given hour of the day
  - These graphs show that the simultaneous flows on the Orrington-South, Surowiec-South, Maine-New Hampshire, and North-South interfaces are consistently flowing in the North to South direction across all cases
    - Within each Scenario, flows on all four interfaces are coherent and of the same general order of magnitude, suggesting that almost all the energy produced north of the Orrington-South or Surowiec-South interfaces flows to the southern portion of the region
  - The SEMA/RI interface is the only one for which flows vary widely between the representative summer and winter days
    - The SEMA/RI area is typically exporting power on the representative summer day as a result of the high concentration of NGCC production in the area
    - The SEMA/RI area is typically importing power on the representative Winter day because some of the SEMA/RI NGCC production is replaced by wind production from outside the area

MW Flows on Interfaces for Summer Peak Hour – All scenarios



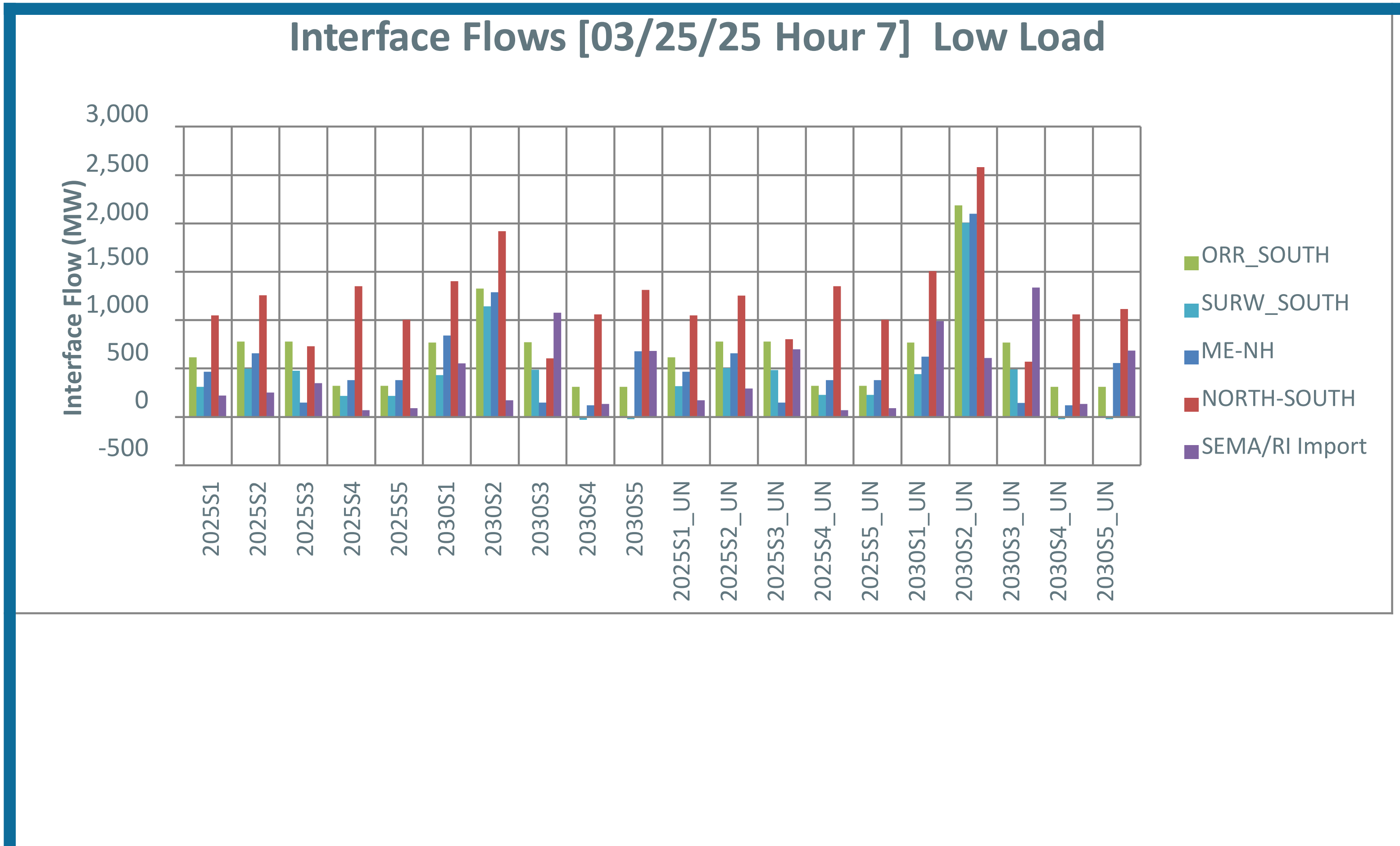
MW Flows on Interfaces for Winter Peak Hour – All Scenarios



Observations From Interface Flows on Representative Low Load Day

- Interface flows on representative low load day, shows the simultaneity of the flows across the various interfaces, in a given hour of the day
  - These graphs show that the simultaneous flows on the Orrington-South, Surowiec-South, Maine-New Hampshire, and North-South interfaces are generally flowing in the North to South direction across all cases. Surowiec-South, however, has very low flows for Scenarios 4 and 5
    - Flows for the constrained and unconstrained cases show similar relative patterns for 2025 and 2030
    - Scenario 2 has the highest utilization of the transmission system, but this is lower than the summer peak day and much lower than the winter peak day
    - Scenario 3 has the highest utilization of SEMA-RI in 2030 as compared with the other scenarios
    - Scenario 4 has the lowest utilization of the Maine interfaces

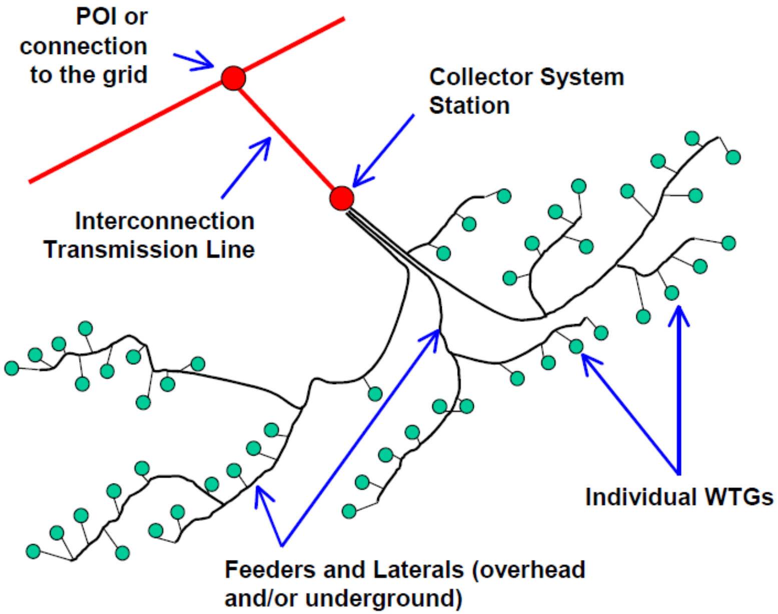
MW Flows on Interfaces for Low Load Hour – All Scenarios



PRELIMINARY HIGH ORDER OF MAGNITUDE TRANSMISSION DEVELOPMENT COSTS

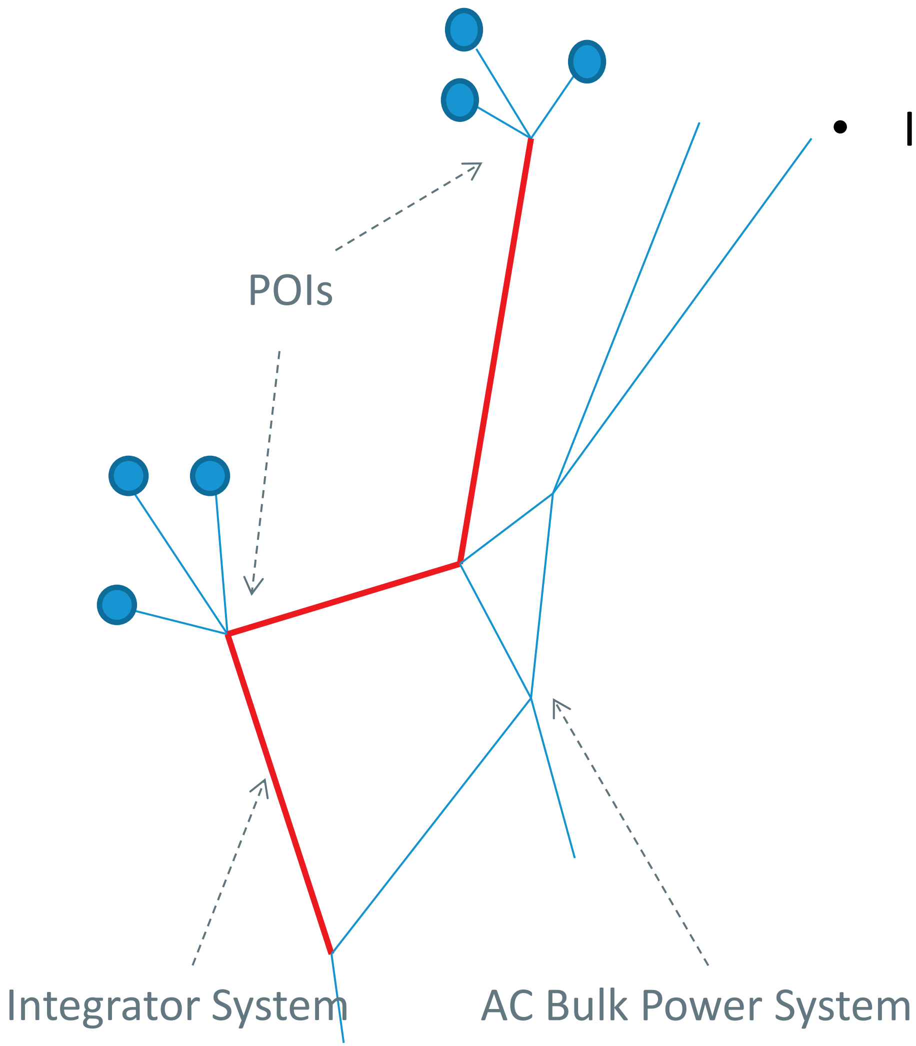
Transmission Needed to Integrate Renewable Resources – Collector and Interconnection System

- Four categories of transmission upgrades are needed to integrate renewable resources



- Plant collector system
  - Transmission system tying each individual wind turbine generator or photovoltaic generator to the collector system station
  - May include generator step-up transformers, collector strings , collector substation, collector step-up transformer, supplemental static and/or dynamic reactive devices
- Interconnection system
  - Transmission system tying the collector system station to the Point of Interconnection (POI)
  - May include high-voltage AC generator lead, high-voltage substation, supplemental static and/or dynamic reactive devices

Transmission Needed to Integrate Renewable Resources – Integrator System



- Integrator system
  - Transmission system tying the POI to the interconnected bulk power system
  - May include new high-voltage AC or DC lines and converter stations and supplemental static and/or dynamic reactive devices
  - Conceptually, similar type of upgrades to those considered in the on-going 2016 Maine Resource Integration Study
    - Available at https://smd.iso-ne.com/operations-services/ceii/pac/2016/09/a3_maine_resource_integration_study.pdf

Transmission Needed to Integrate Renewable Resources – Congestion Relief System

- Congestion relief system
  - Transmission system that allows the removal of 100% of the transmission congestions that prevent full energy production from the renewable resources
  - Assume HVDC tie(s) tying the integrator system to the system's hub, located at Millbury, MA
    - HVDC tie(s) sized to remove congestions observed in the energy production runs
    - Ancillary devices/services to control impact of high penetration of converter based resources
      - Special controls on power electronic devices
      - High inertia synchronous condensers
      - System protection upgrades
      - Additional battery storage

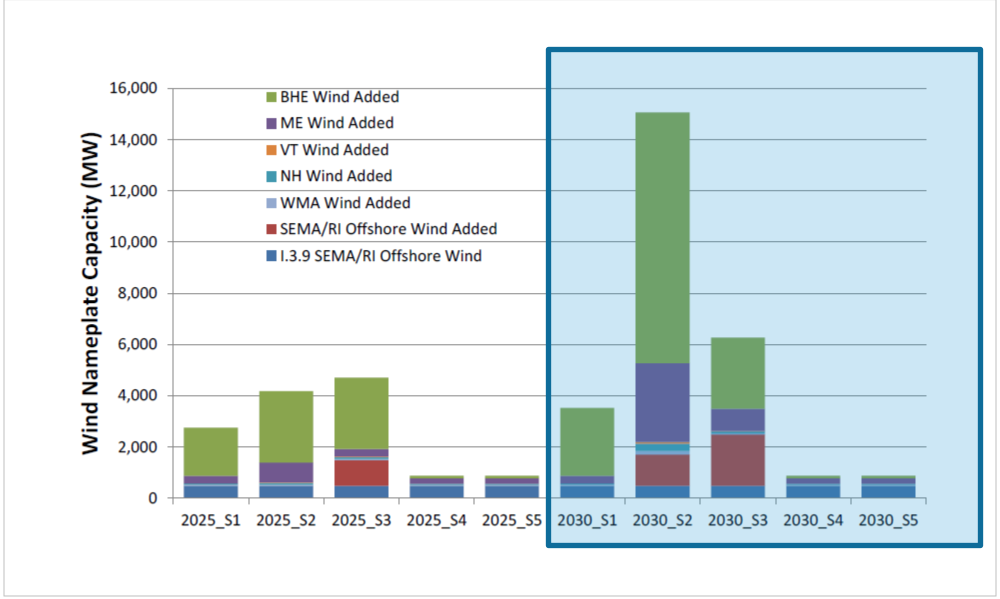
Cost Estimates For Renewable Resources Integration - Assumptions

- A full cost estimate would include costs for all four categories of transmission upgrades
  - Plant collector system
  - Interconnection system
  - Integrator system
  - Congestion relief system
- Plant collector and interconnection system costs are specific to each generation interconnection project
  - They will not be addressed as part of this presentation
- Integrator and congestion relief system costs depend on the design of the integrator and congestion relief systems
- The amount of renewable injections in Scenarios 4 and 5 is very small (see next slides)
  - No cost estimates are developed for these two scenarios

Sizing and Cost of the Integrator System

- For the purpose of this costing exercise, it is assumed that the size of the integrator system will be proportional to the size of the nameplate renewable injection

Scenarios Number	1	2	3	4	5
2030 Maine Nameplate Wind Injections	2,955	12,872	3,652	308	308



Slide 14 - August PAC presentation, available at https://www.iso-ne.com/static-assets/documents/2016/08/a6_2016_economic_study_draft_results.pdf

Sizing and Cost of the Integrator System

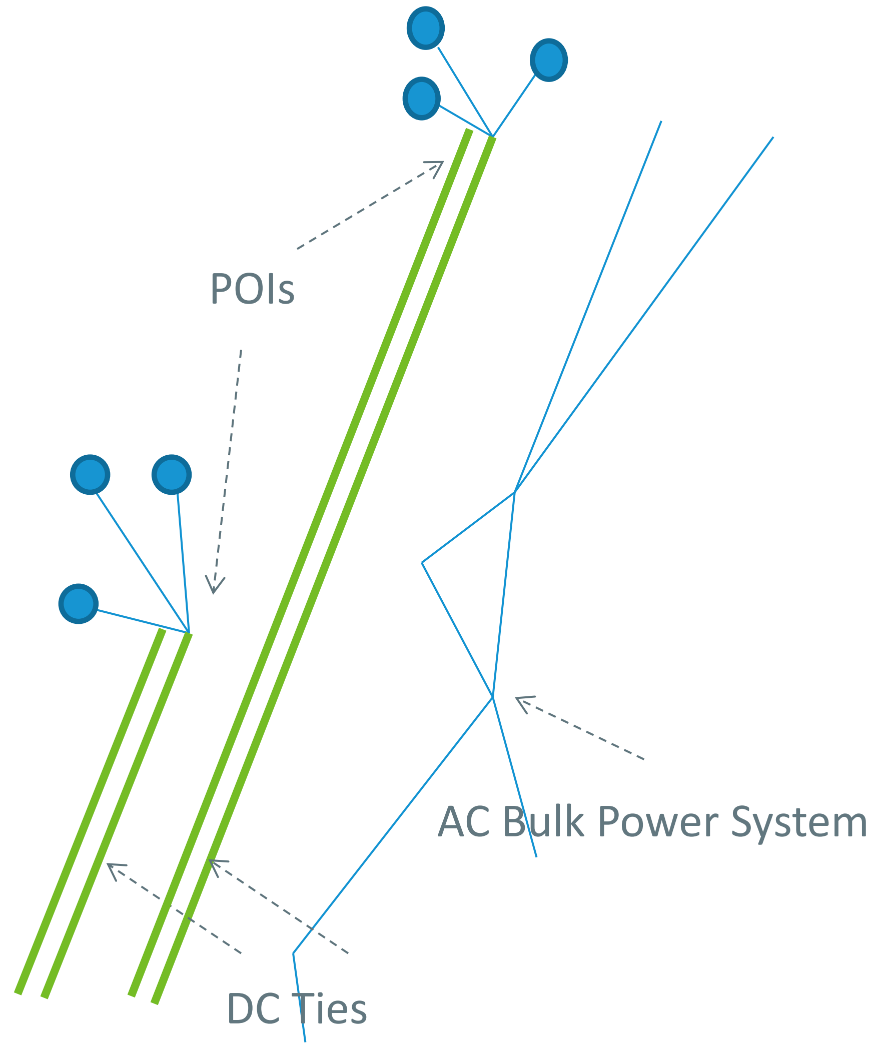
- Scenario 1
  - The size of the Maine renewable injection is somewhat commensurate to what is being considered in the 2016 Maine Resource Integration Study
    - Detailed costs estimates for the conceptual AC transmission upgrades considered in the study will be shared with the PAC in late 2016 or early 2017
    - However, the infrastructure being studied may not be capable of interconnecting 3,000 MW
  - Expected high-level estimates are in $1.5 billion range for the parallel 345 kV transmission path of the combination option

- Scenario 3
  - The size of the Maine renewable injection is larger to what is being considered in the 2016 Maine Resource Integration Study
  - Assuming that the conceptual AC transmission upgrades would have to be doubled to form two parallel 345 kV transmission paths, expected high-level estimates are in the $3 billion range

Costs described here are preliminary high-level order of magnitude costs and are based on judgement.
Also, they do not account for individual plants' interconnection costs or potential costs from system operational issues.

Sizing of the Integrator System, cont.

- Scenario 2
  - The size of the Maine renewable injection is over five times larger than what is being considered in the 2016 Maine Resource Integration Study
    - For such a tremendously large injection, it is assumed that no AC integrator system could be designed to tie the POI into the interconnected bulk power system without a complete overhaul of the AC bulk power system
    - Instead, we assume that the renewable resources will be tied directly into several DC connectors that will also serve as congestion relief systems



Sizing of the Congestion Relief System

- The MW congestion relief need is based on on-peak conditions (Winter and Summer)
- It is the difference in interface flows between the 2030 unconstrained and constrained scenarios
  - See slides 20 and 21 for reference
  - For example, in scenario 1, the ME-NH flow in the winter peak hour is 3,285 MW in the unconstrained case and 1,814 MW in the constrained case. The congestion relief need on the ME-NH interface is 1,471 MW
- The total need is based on the highest simultaneous need across all northern interfaces
  - Surowiec-South, ME-NH and North-South interfaces

Needed Congestion Relief Capacity	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
2030 Winter Peak	1,471 MW	9,043 MW	1,839 MW	8 MW	36 MW
2030 Summer Peak	603 MW	3,854 MW	500 MW	8 MW	8 MW
Higher of Winter/Summer	**1,471 MW**	**9,043 MW**	**1,839 MW**	**8 MW**	**36 MW**

Characteristics of the Congestion Relief System

- For the purpose of this analysis, we assumed that the congestion relief system would be composed of
  - DC portion: parallel overhead HVDC ties
    - Bipolar design
    - Voltage-source converters (VSC)
    - 1,200 MW capacity
      - To respect 1,200 MW New England loss of source
      - Among largest capacities seen for VSC technology
    - DC voltage of 300/320 kV
    - Assumed HVDC costs:
      - Converter: $300 million/converter
      - DC line: $3.5 million/mile
      - Miscellaneous costs for additional control, filters, undergrounding or right-of-way requirements: $200 million/tie
  - Ancillary AC upgrades
    - Fast-responding dynamic reactive devices
    - 345 kV substation and network upgrades

Costs described here are preliminary high-level order of magnitude costs and are based on judgement.
Also, they do not account for individual plants' interconnection costs or potential costs from system operational issues.

Ancillary AC Upgrades Associated with the Congestion Relief System

- Sending end
  - Fast-responding dynamic reactive devices
    - Synchronous condensers (to increase system's short circuit strength)

    or
    - Statcom devices (to maintain system's voltage performance)
    - Assumed to be part of the integrator system, except for Scenario 2
      - Assumed need of 1/3 of MW capability
      - Assumed cost of $0.25 million/MVAR
  - 345 kV substation upgrades
    - Assumed $10 million per terminal expansion in Scenarios 1 and 3
    - Assumed $40 million per new substation (to connect the POIs to the converter station at each HVDC station) in Scenario 2

- Receiving end
  - Fast-responding dynamic reactive devices in all three scenarios
    - Assumed need of 1/3 of MW capability
    - Assumed cost of $0.25 million/MVAR
  - 345 kV substation upgrades
    - Assumed cost of $10 million per terminal expansion in all scenarios
  - 345 kV system upgrades on receiving network
    - Assumed additional generic cost of $500 million in Scenarios 1 and 3 and $1.5 billion in Scenario 2

Costs described here are preliminary high-level order of magnitude costs and are based on judgement.
Also, they do not account for individual plants' interconnection costs or potential costs from system operational issues.

Total Cost Breakdown of the Congestion Relief System

Congestion Relief System		Scenario 1 1,471 MW (2 HVDC Ties)		Scenario 2 9,043 MW (8 HVDC Ties)		Scenario 3 1,839 MW (2 HVDC Ties)	
Equipment	$ per Unit	Quantities	Total $	Quantities	Total $	Quantities	Total $
DC Portion							
HVDC Overhead Lines	$3.5 million/mile	2 * 200 = 400 mi.	$1.4 bn	5 * 400 + 3 * 300 = 2900 mi.	$10.15 bn	2 * 200 = 400 mi.	$1.4 bn
Converters	$300 million/converter	4	$1.2 bn	16	$4.8 bn	4	$1.2 bn
Misc. DC Additional Equipment	$200 million/tie	2	$0.4 bn	8	$1.6 bn	2	$0.4 bn
Total – DC Portion	--	--	$3 bn	--	$16.55 bn	--	$3 bn
AC Portion							
Sending End - Reactive Devices	$0.25 million/MVAR	-- (included in integrator system)	--	Approx. 1/3 * 9,000 = 3000 MVAR	$0.75 bn	-- (included in integrator system)	--
Sending End – AC Terminations	$10 million/terminal expansion (assumed 2 terminal expansions per tie)	2 * 2 = 4	$0.04 bn	--	--	2 * 2 = 4	$0.04 bn
Sending End – New AC Substations	$40 million/AC substation	-- (included in integrator system)	--	8 (to connect POI to converter station at each tie)	$0.32 bn	-- (included in integrator system)	--
Receiving End - Reactive Devices	$0.25 million/MVAR	Approx. 1/3 * 1500 = 500 MVAR	$0.13 bn	Approx. 1/3 * 9,000 = 3000 MVAR	$0.75 bn	Approx. 1/3 * 1800 = 600 MVAR	$0.15 bn
Receiving End – AC Terminations	$10 million/terminal expansion (assumed 2 terminal expansions per tie)	2 * 2 = 4	$0.04 bn	8 * 2 = 16	$0.16 bn	2 * 2 = 4	$0.04 bn
Receiving End – Additional Upgrades on AC Network	Assumed generic cost for each scenario	--	$0.5 bn	--	$1.5 bn	--	$0.5 bn
Total – AC Portion	--	--	$0.71 bn	--	$3.48 bn	--	$0.73 bn
AC and DC Portions							
Total – Congestion Relief System	--	--	$3.71 bn	--	$20.03 bn	--	$3.73 bn

Costs described here are preliminary high-level order of magnitude costs and are based on judgement.
Also, they do not account for individual plants' interconnection costs or potential costs from system operational issues.

DC Portion of the Congestion Relief System

	Scenario 1	Scenario 2	Scenario 3
Congestion Relief Capacity (MW)	1,471 MW	9,043 MW	1,839 MW
Technology	HVDC - 1200 MW VSC, Bipolar	HVDC - 1200 MW VSC, Bipolar	HVDC - 1200 MW VSC, Bipolar
Number of HVDC Ties	2	8	2
Topology	Interconnected to AC system Connecting Larrabee 345 kV to the Millbury hub	Radial Connecting POIs directly to the Millbury hub	Interconnected to AC system Connecting Larrabee 345 kV to the Millbury hub
Mileage	200 mi.	400 mi. (5 ties - for POIs in Aroostook/Penobscot counties) 300 mi. (3 ties for POIs in Somerset/Franklin counties)	200 mi.
Number of Converters	4	16	4
Misc. Additional Costs	$0.4 bn	$1.6 bn	$0.4 bn
Cost for the DC portion	$3 bn	$16.55 bn	$3 bn

Costs described here are preliminary high-level order of magnitude costs and are based on judgement.
Also, they do not account for individual plants' interconnection costs or potential costs from system operational issues.

AC Portion of the Congestion Relief System

	Scenario 1	Scenario 2	Scenario 3
Congestion Relief Capacity (MW)	1,471 MW	9,043 MW	1,839 MW
Number of HVDC Ties	2	8	2
Sending End			
Reactive Devices	--	3000 MVAR	--
AC Terminations	4	--	4
New AC Substations	--	8	--
Total AC portion – sending end	$0.04 bn	$1.07 bn	$0.04 bn
Receiving End			
Reactive Devices	500 MVAR	3000 MVAR	600 MVAR
AC Terminations	4	16	4
Additional upgrades on AC network	0.5	1.5	0.5
Total AC portion – receiving end	$0.67 bn	$2.41 bn	$0.69 bn

Costs described here are preliminary high-level order of magnitude costs and are based on judgement. Also, they do not account for individual plants' interconnection costs or potential costs from system operational issues.

SUMMARY

Summary

- The cost analysis in this presentation focuses on the cost of integrating the Maine renewable resources
- Due to the very small amount of renewable injections and negligible need for congestion relief in Scenarios 4 and 5, no cost estimates were developed for these two scenarios
- High level order of magnitude costs were developed for scenarios 1 through 3
- These costs are high level order of magnitude since they were developed based on a very high-level, un-tested, view of the necessary transmission expansion needed to accommodate renewable integration
- In other presentation, the ISO has identified potential transmission planning issues that will need to be addressed for the development of large-scale inverter based resources, including operational issues presented by off-peak load periods
  - Regulation, ramping, and reserves
  - Low short circuit availability, power quality, voltage control, stability performance
  - Control interactions between many power electronic devices
- The costs presented in this presentation do not fully account for all of those transmission planning issues

Summary, cont.

	Scenario 1	Scenario 2	Scenario 3
2030 Maine Nameplate Wind Injection (MW)	2,955 MW	12,872 MW	3,652 MW
Needed Congestion Relief Capacity (MW)	1,471 MW	9,043 MW	1,839 MW
Integrator System (Description)	1 AC parallel 345 kV path	---	2 AC parallel 345 kV paths
Integrator System (Cost $ Bn)	1.5	---	3
Congestion Relief System (Description)	Connecting Larrabee 345 kV to the Millbury hub	Connecting POIs directly to the Millbury hub	Connecting Larrabee 345 kV to the Millbury hub
Congestion Relief System (Cost $ Bn)	3.7	20.0	3.7
Total Cost ($ Bn)	5.2	20.0	6.7
Total Cost ($ Bn) + 50% margin	7.8	30.0	10.0

Costs described here are preliminary high-level order of magnitude costs and are based on judgement.
Also, they do not account for individual plants' interconnection costs or potential costs from system operational issues.

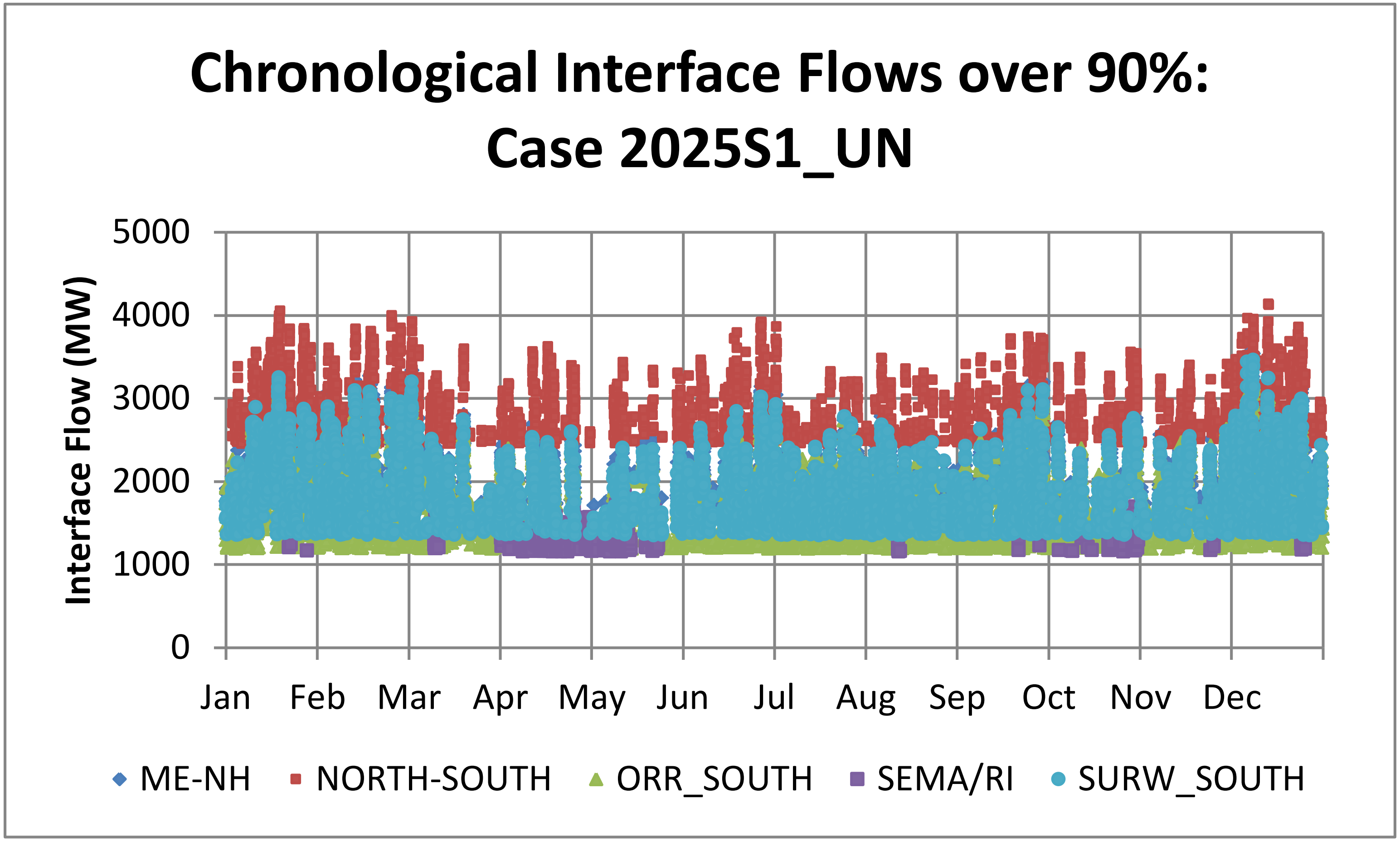
APPENDIX – TRANSMISSION FLOW RESULTS

Appendix - September PAC Presentation

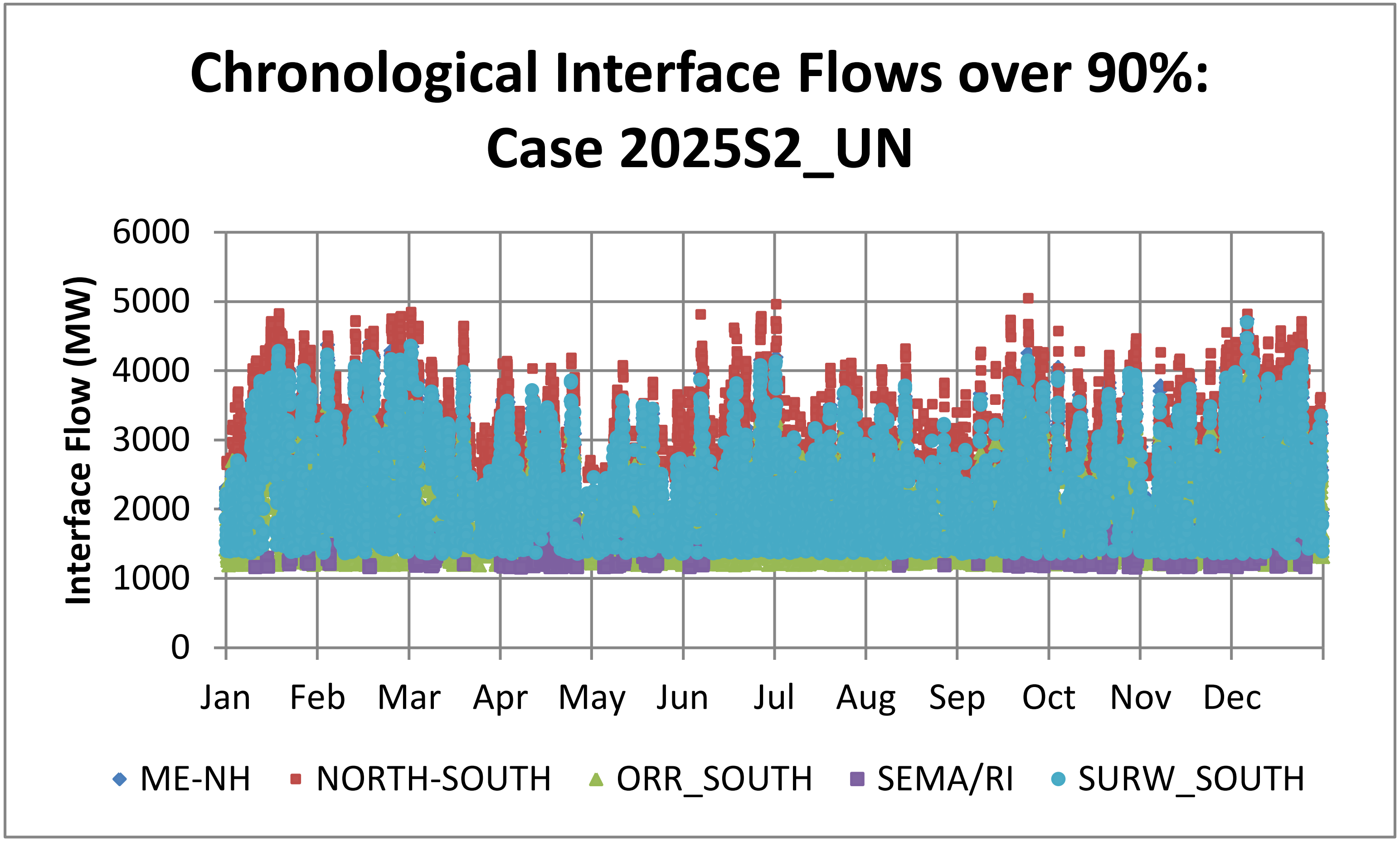
CHRONOLOGICAL INTERFACE FLOWS

Exceeds 90% of Rating

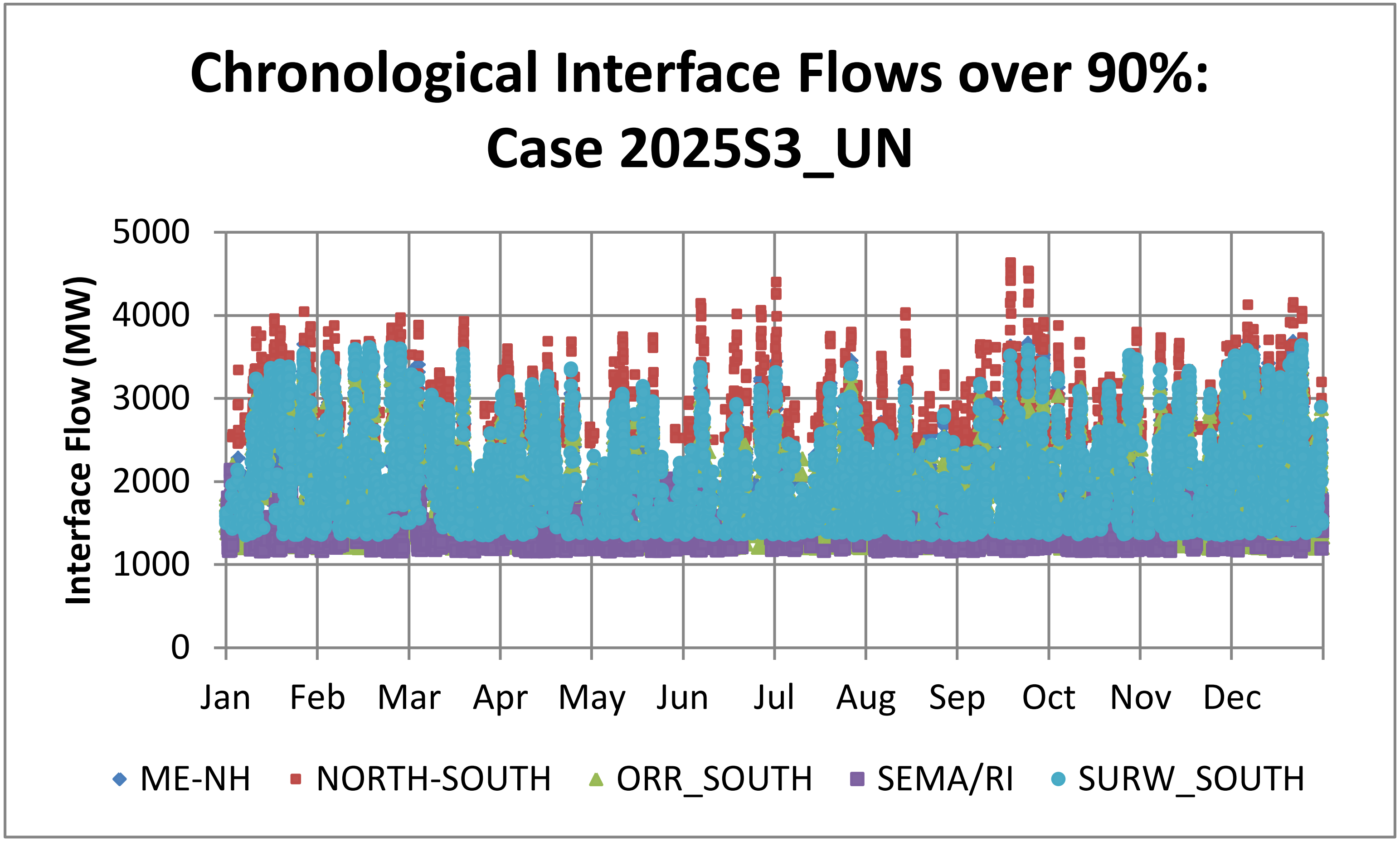
Chronological Interface Flows Exceeds 90% of Rating: 2025 Unconstrained Scenario 1



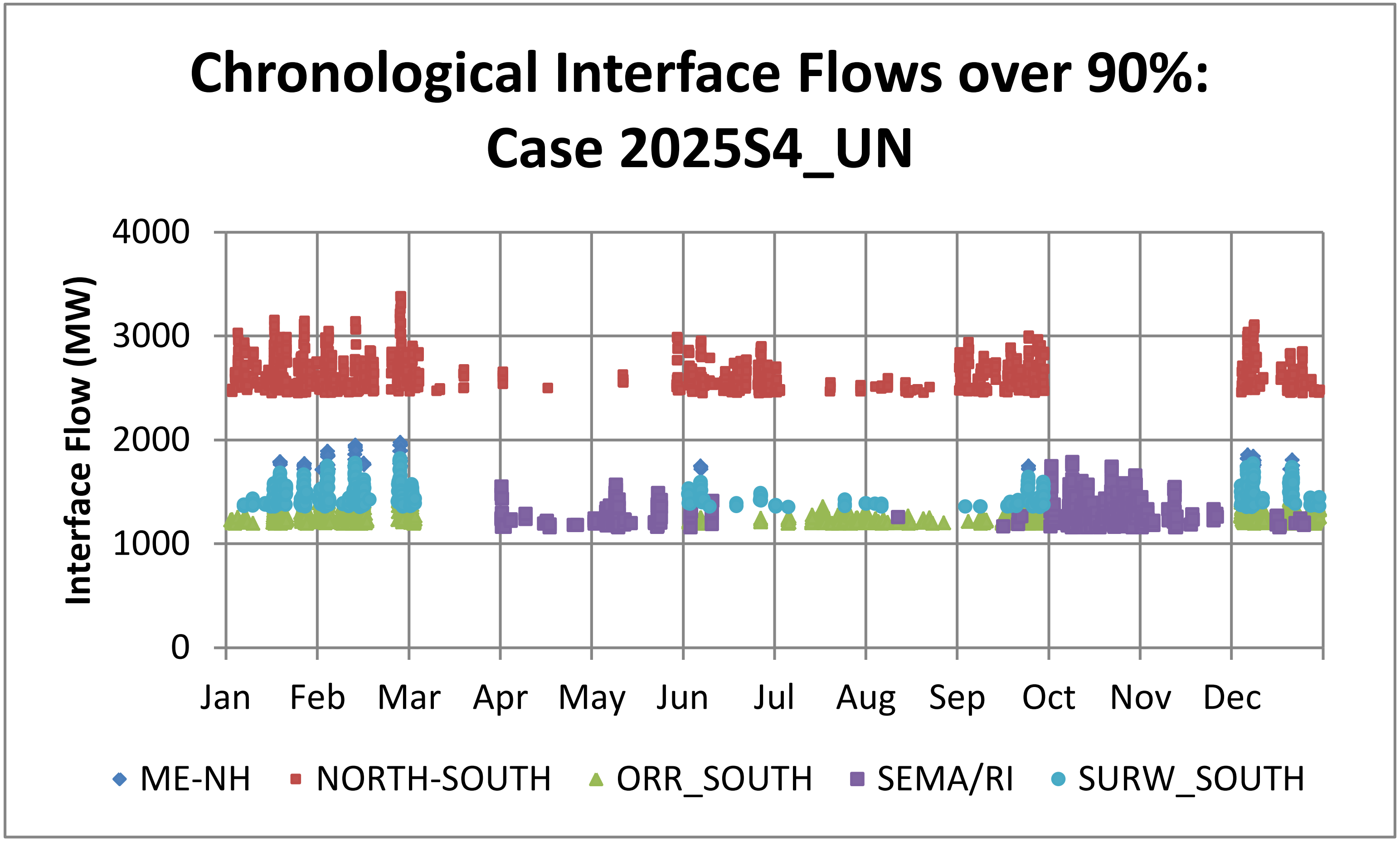
Chronological Interface Flows Exceeds 90% of Rating: 2025 Unconstrained Scenario 2



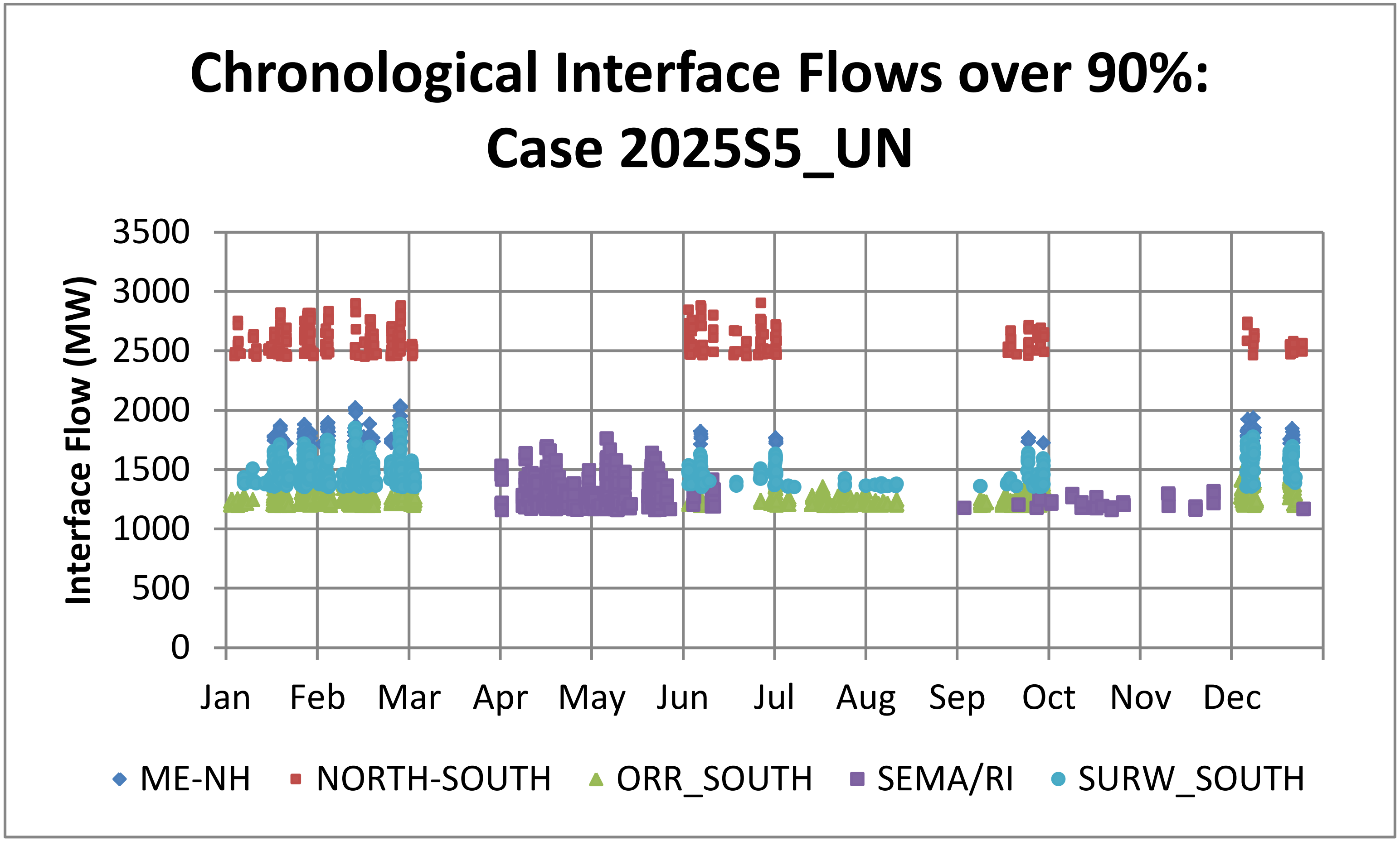
Chronological Interface Flows Exceeds 90% of Rating: 2025 Unconstrained Scenario 3



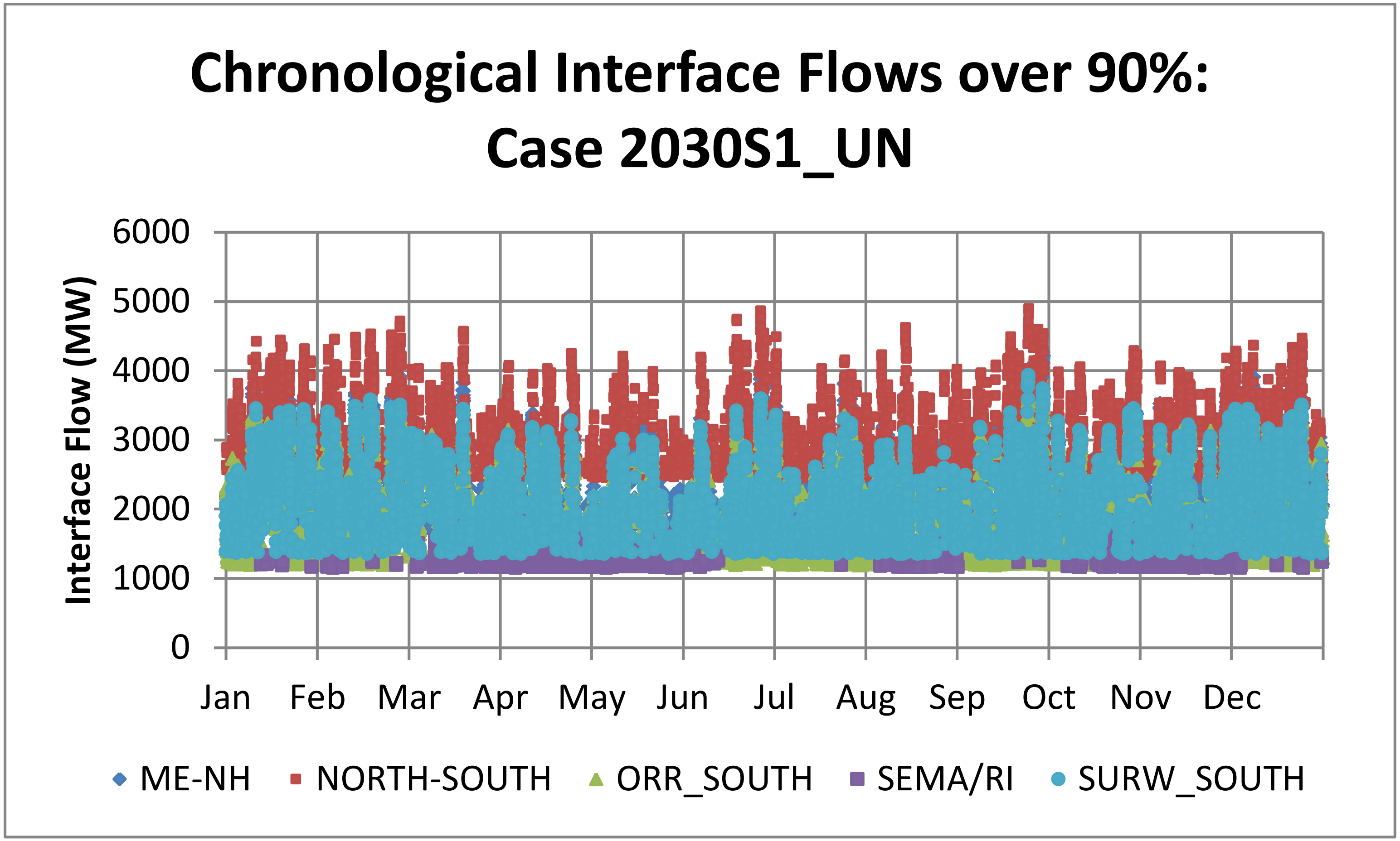
Chronological Interface Flows Exceeds 90% of Rating: 2025 Unconstrained Scenario 4



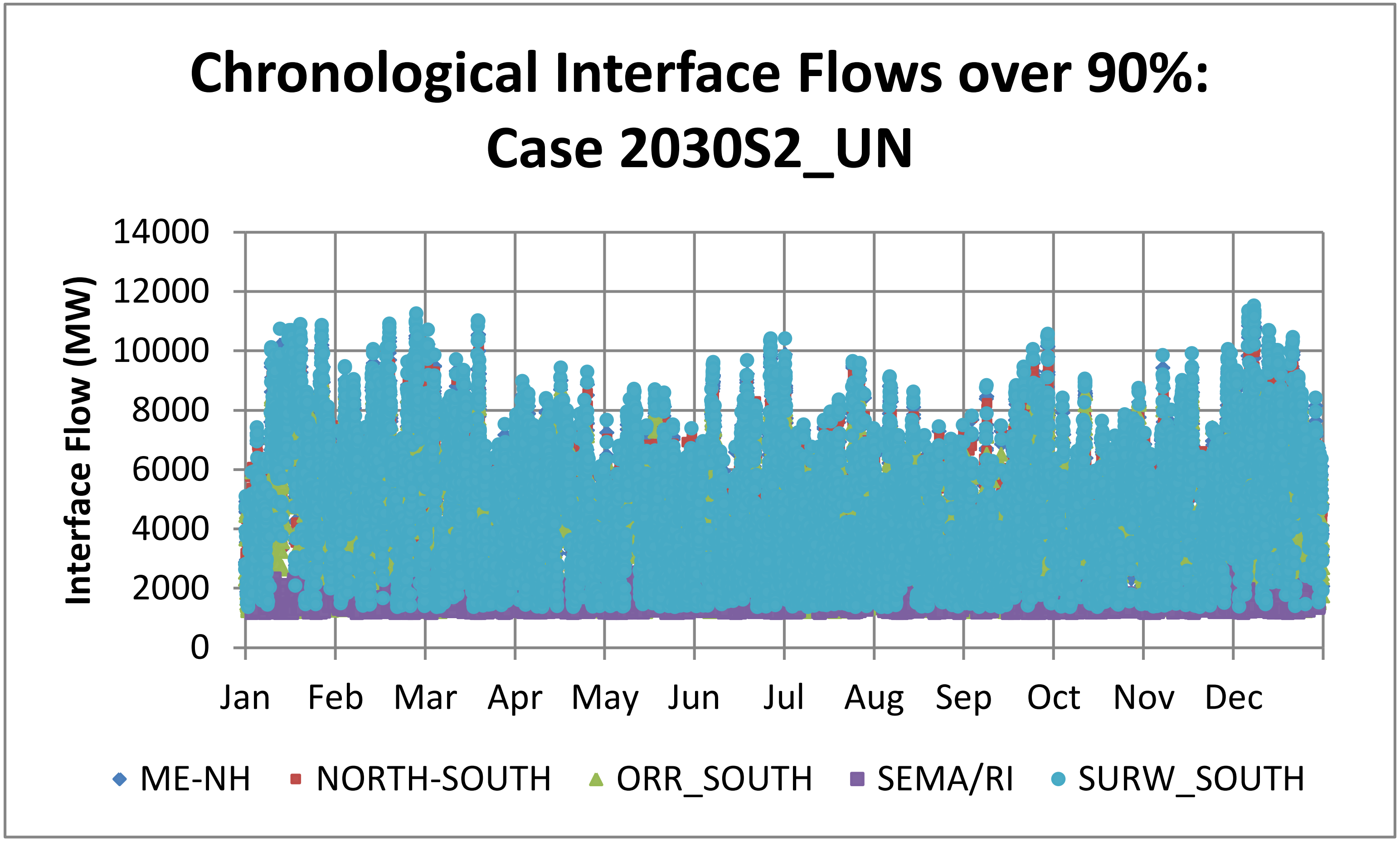
Chronological Interface Flows Exceeds 90% of Rating: 2025 Unconstrained Scenario 5



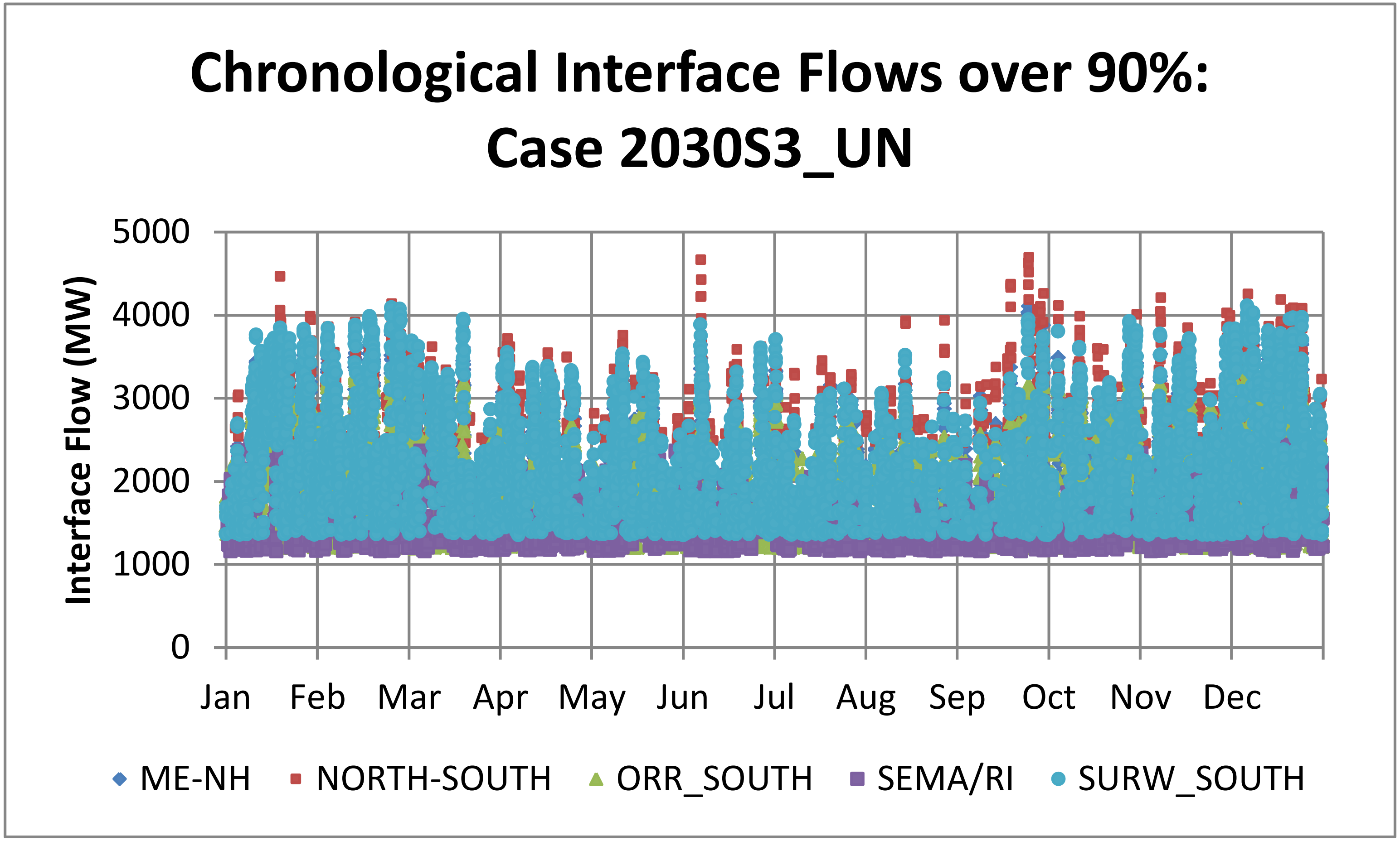
Chronological Interface Flows Exceeds 90% of Rating: 2030 Unconstrained Scenario 1



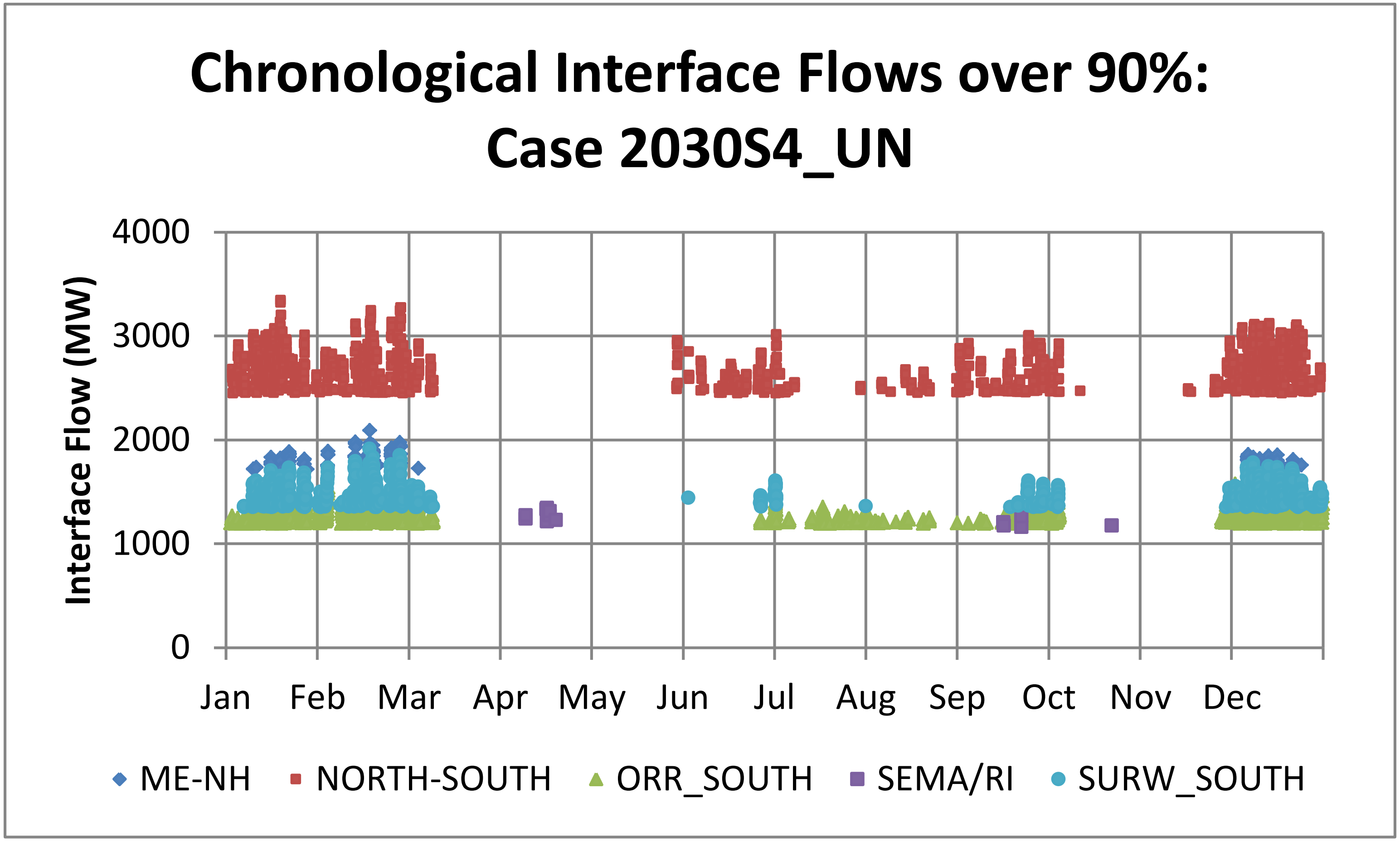
Chronological Interface Flows Exceeds 90% of Rating: 2030 Unconstrained Scenario 2



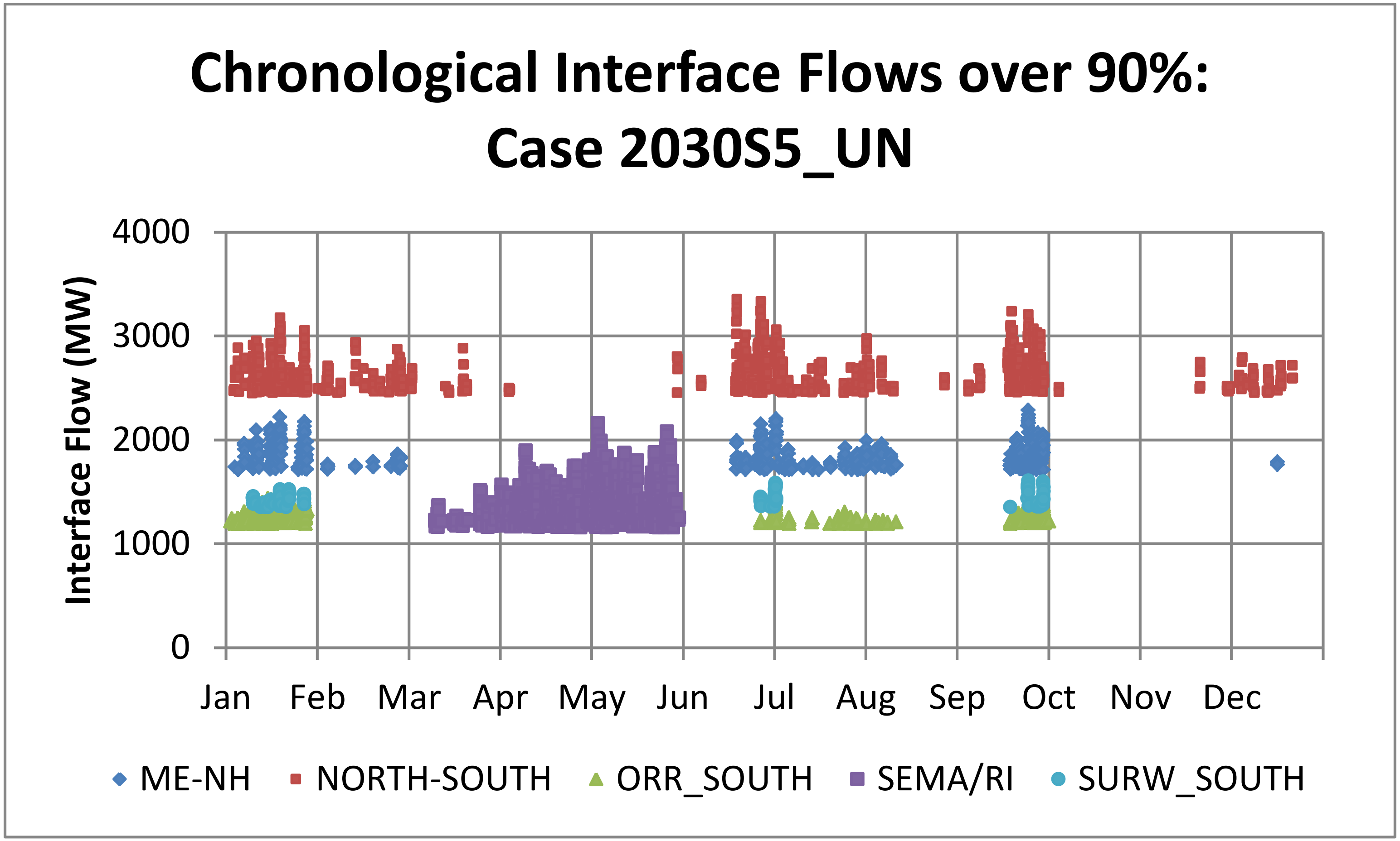
Chronological Interface Flows Exceeds 90% of Rating: 2030 Unconstrained Scenario 3



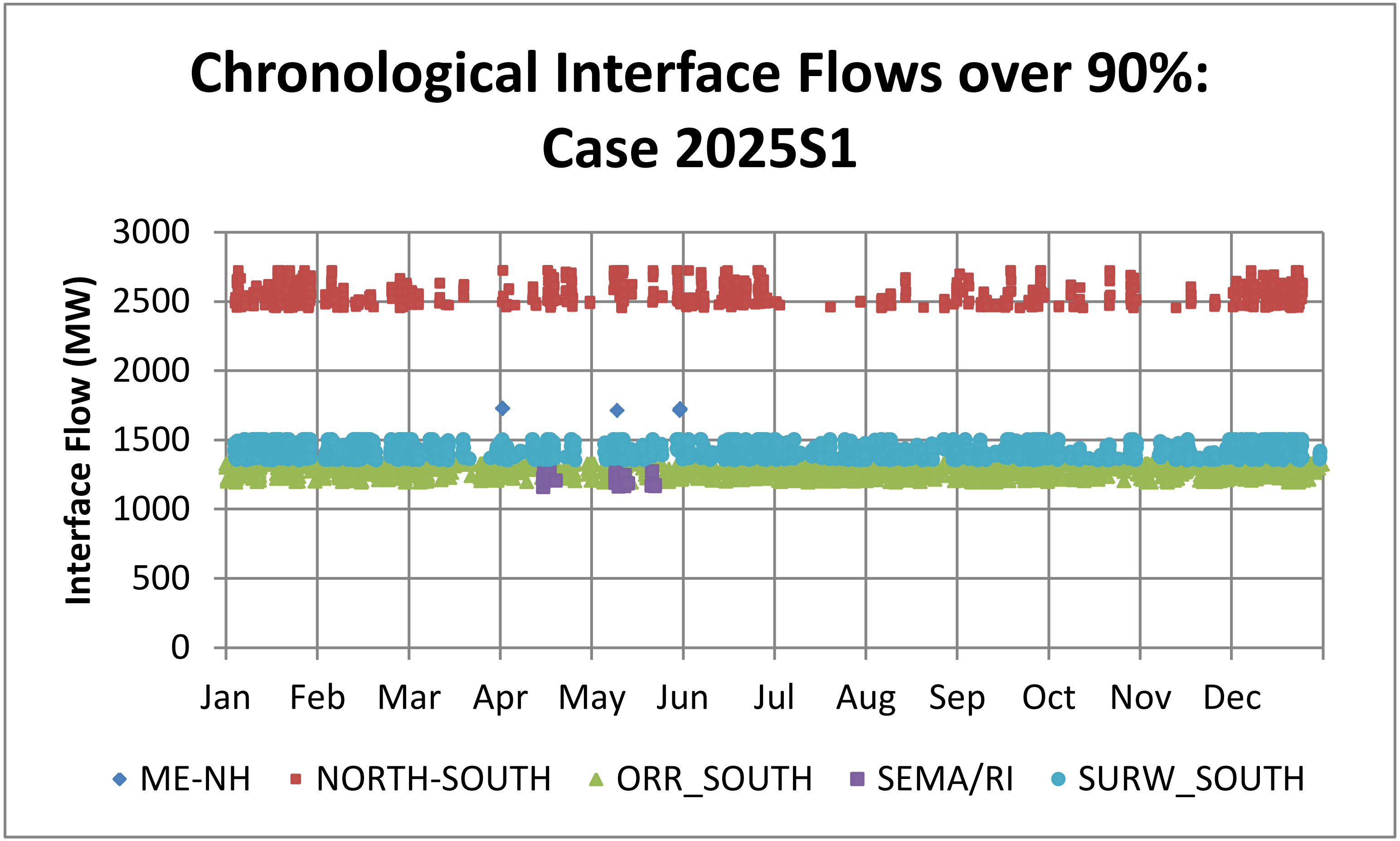
Chronological Interface Flows Exceeds 90% of Rating: 2030 Unconstrained Scenario 4



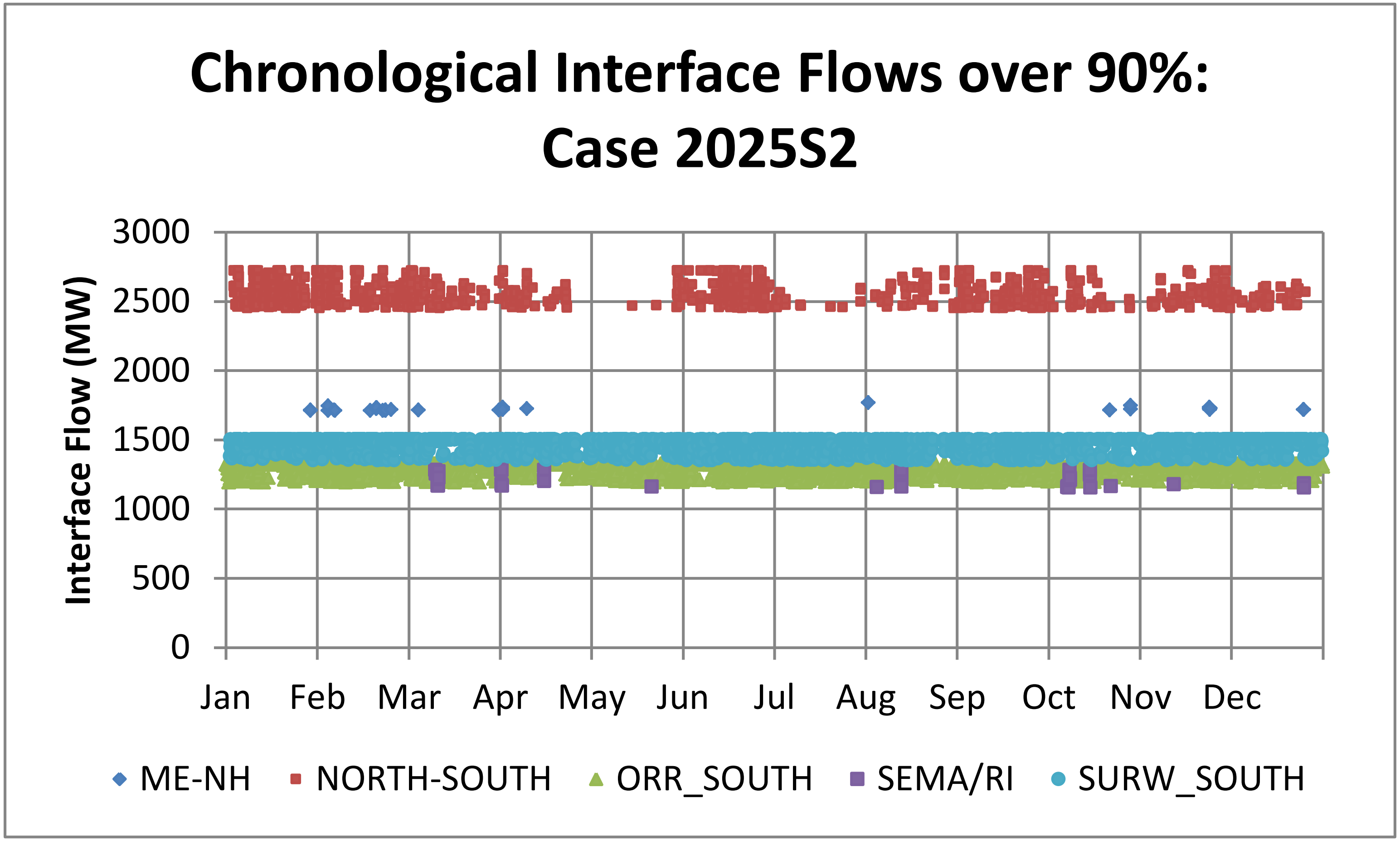
Chronological Interface Flows Exceeds 90% of Rating: 2030 Unconstrained Scenario 5



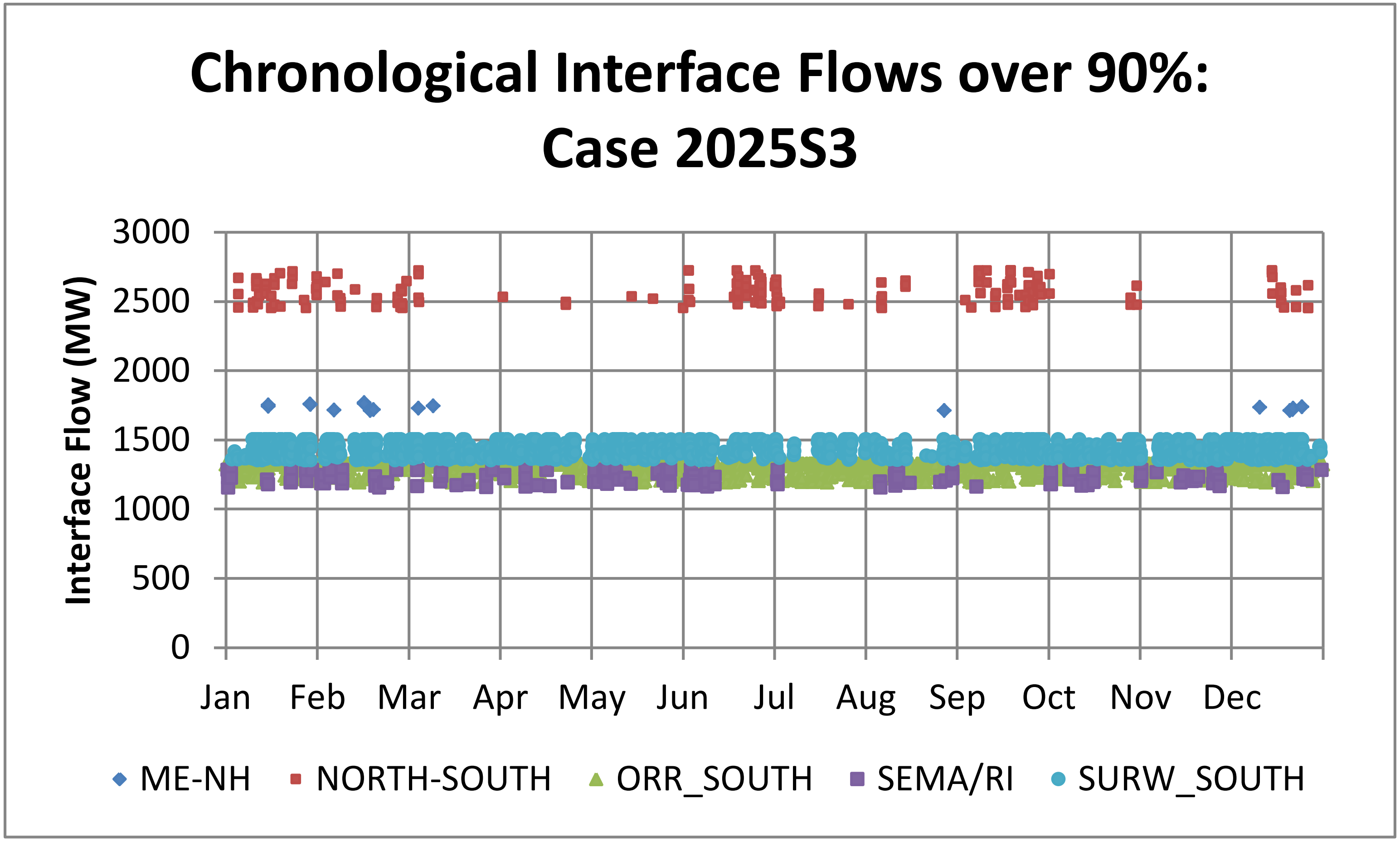
Chronological Interface Flows Exceeds 90% of Rating: 2025 Constrained Scenario 1



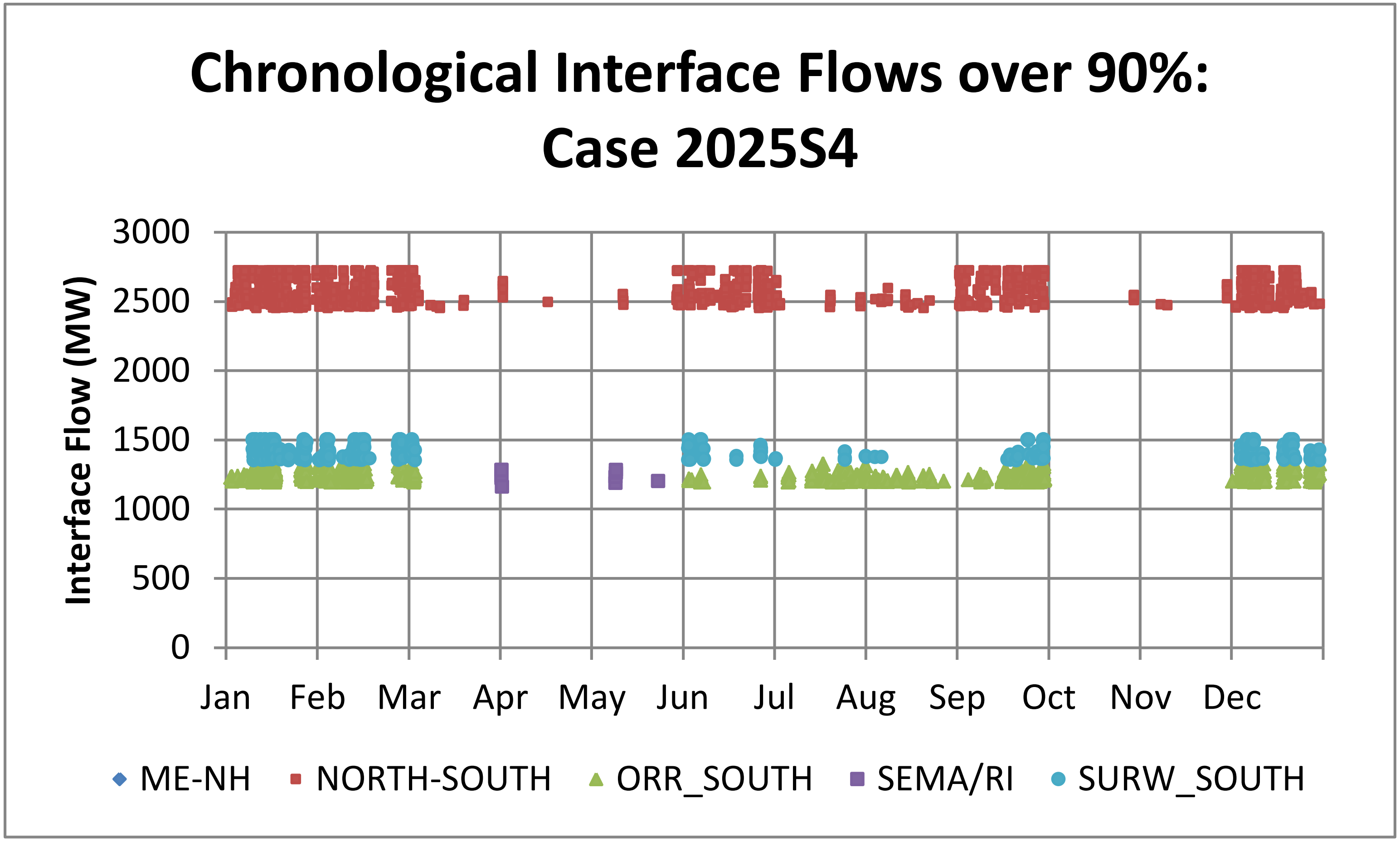
Chronological Interface Flows Exceeds 90% of Rating: 2025 Constrained Scenario 2



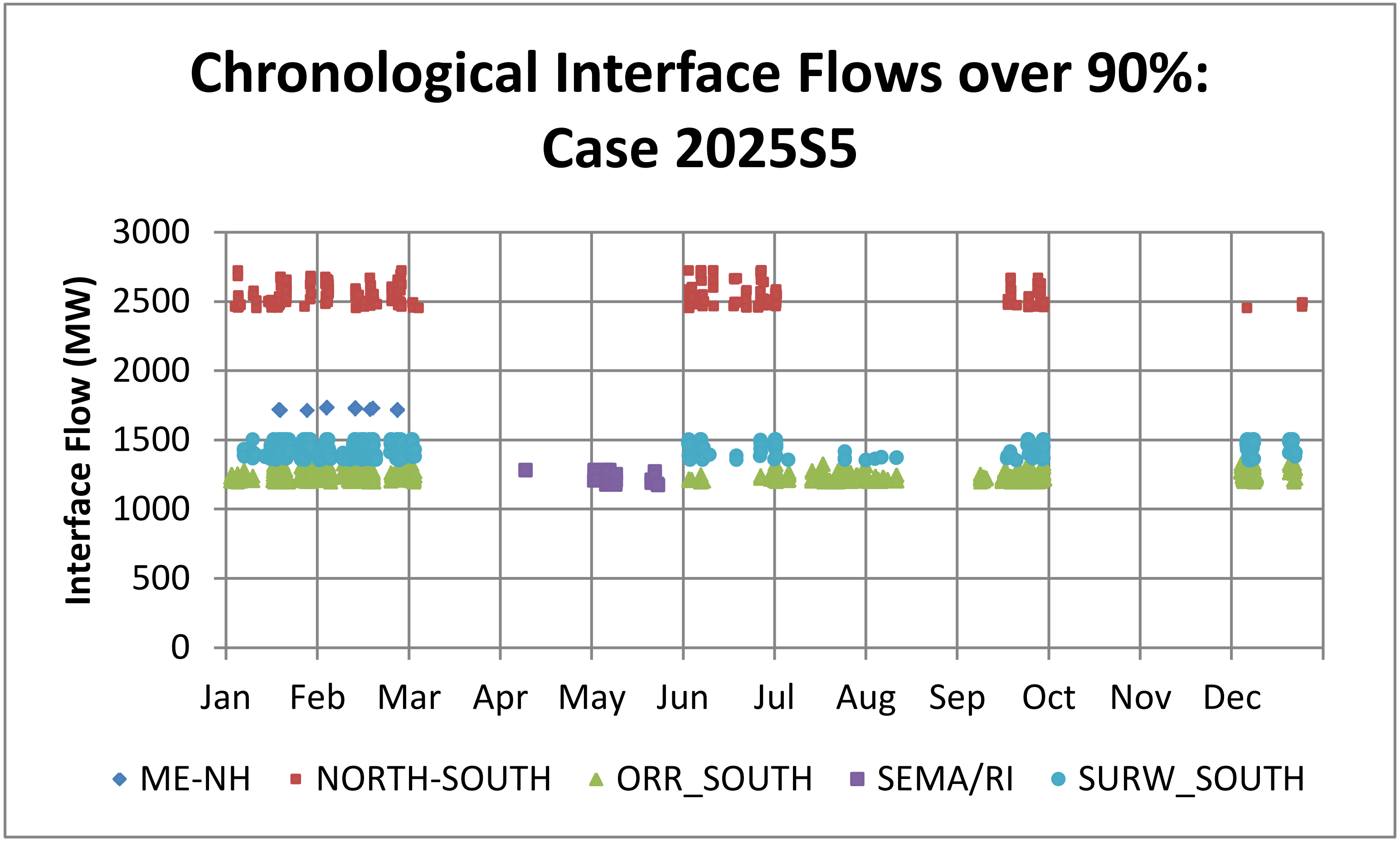
Chronological Interface Flows Exceeds 90% of Rating: 2025 Constrained Scenario 3



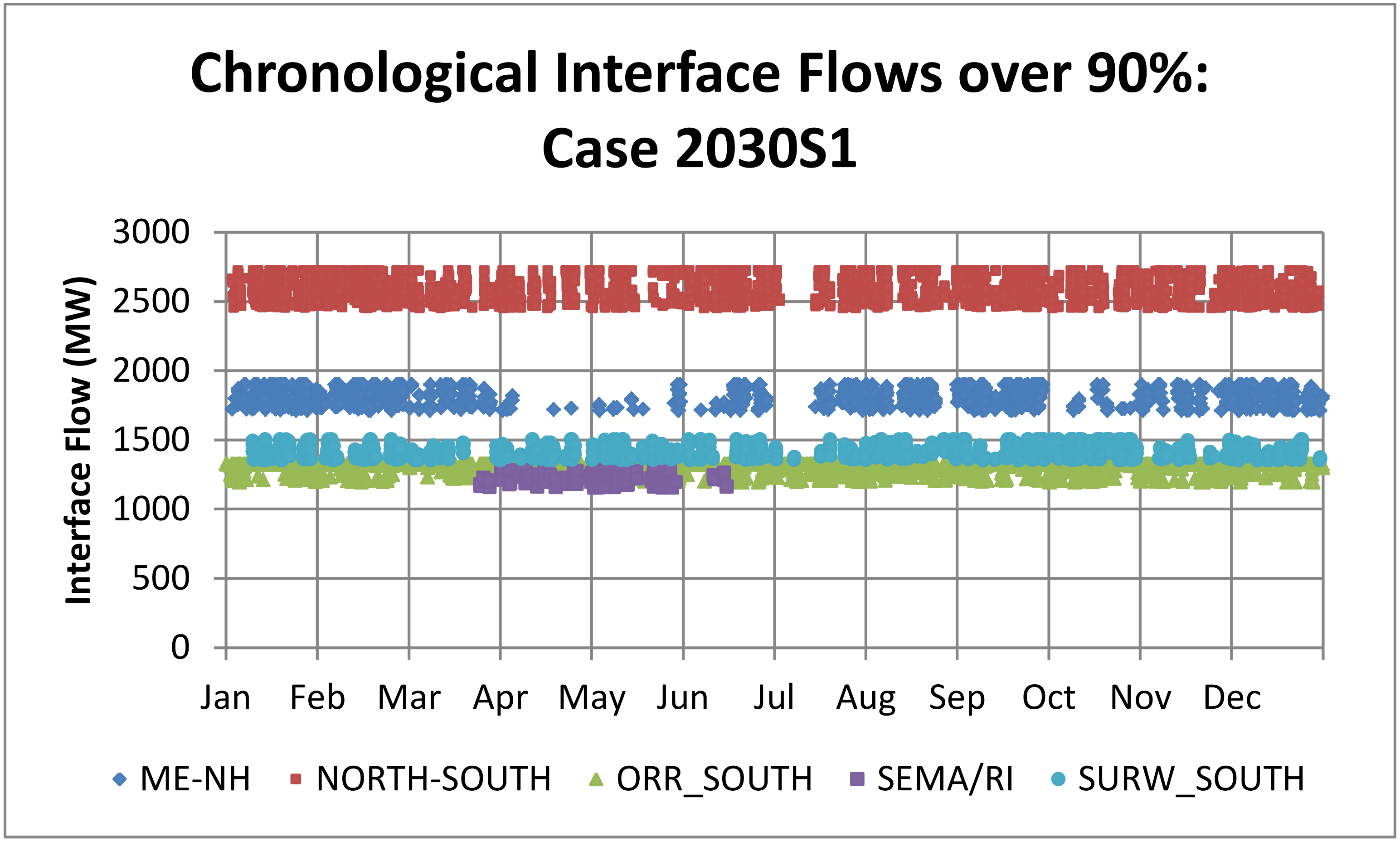
Chronological Interface Flows Exceeds 90% of Rating: 2025 Constrained Scenario 4



Chronological Interface Flows Exceeds 90% of Rating: 2025 Constrained Scenario 5



Chronological Interface Flows Exceeds 90% of Rating: 2030 Constrained Scenario 1



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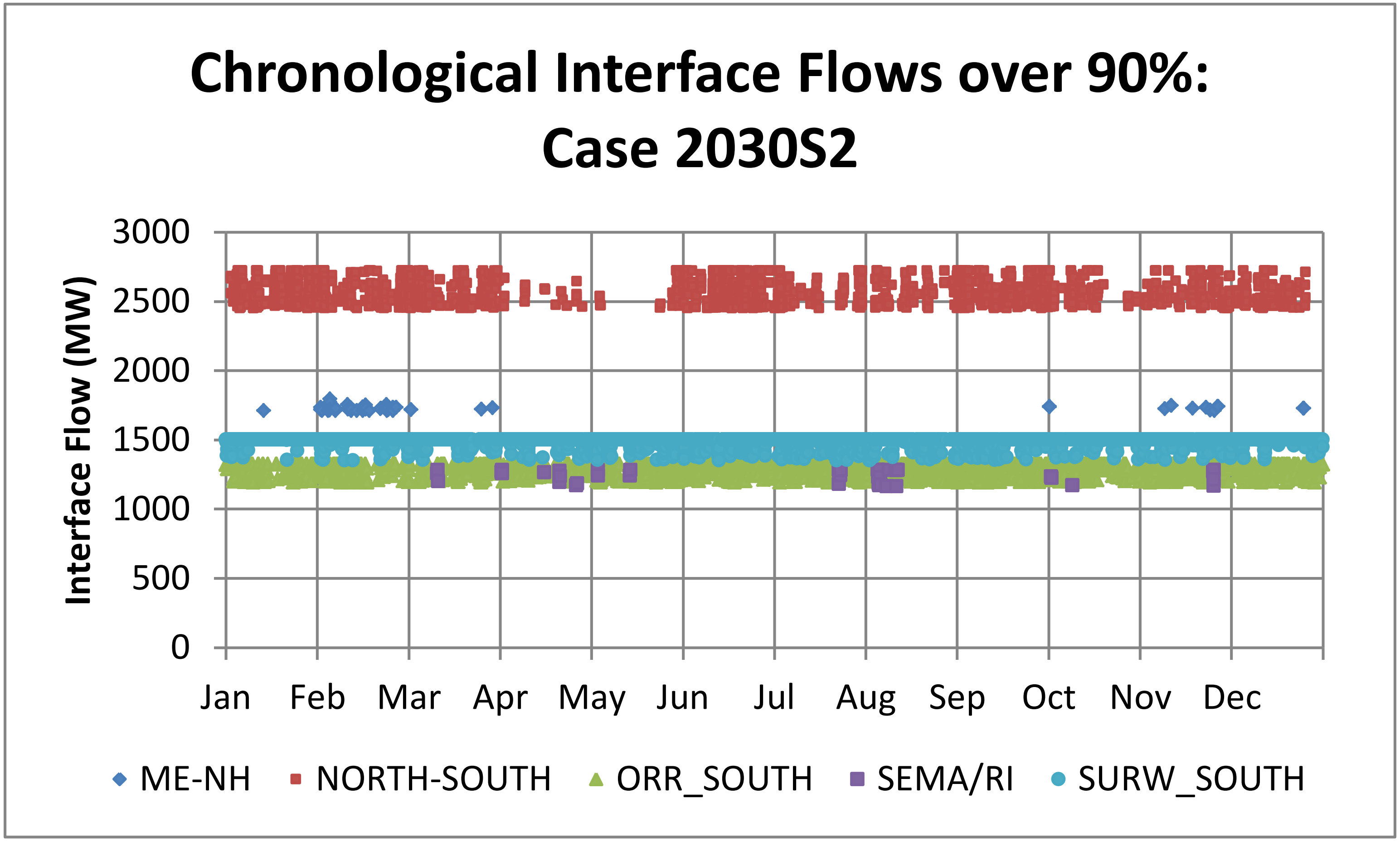
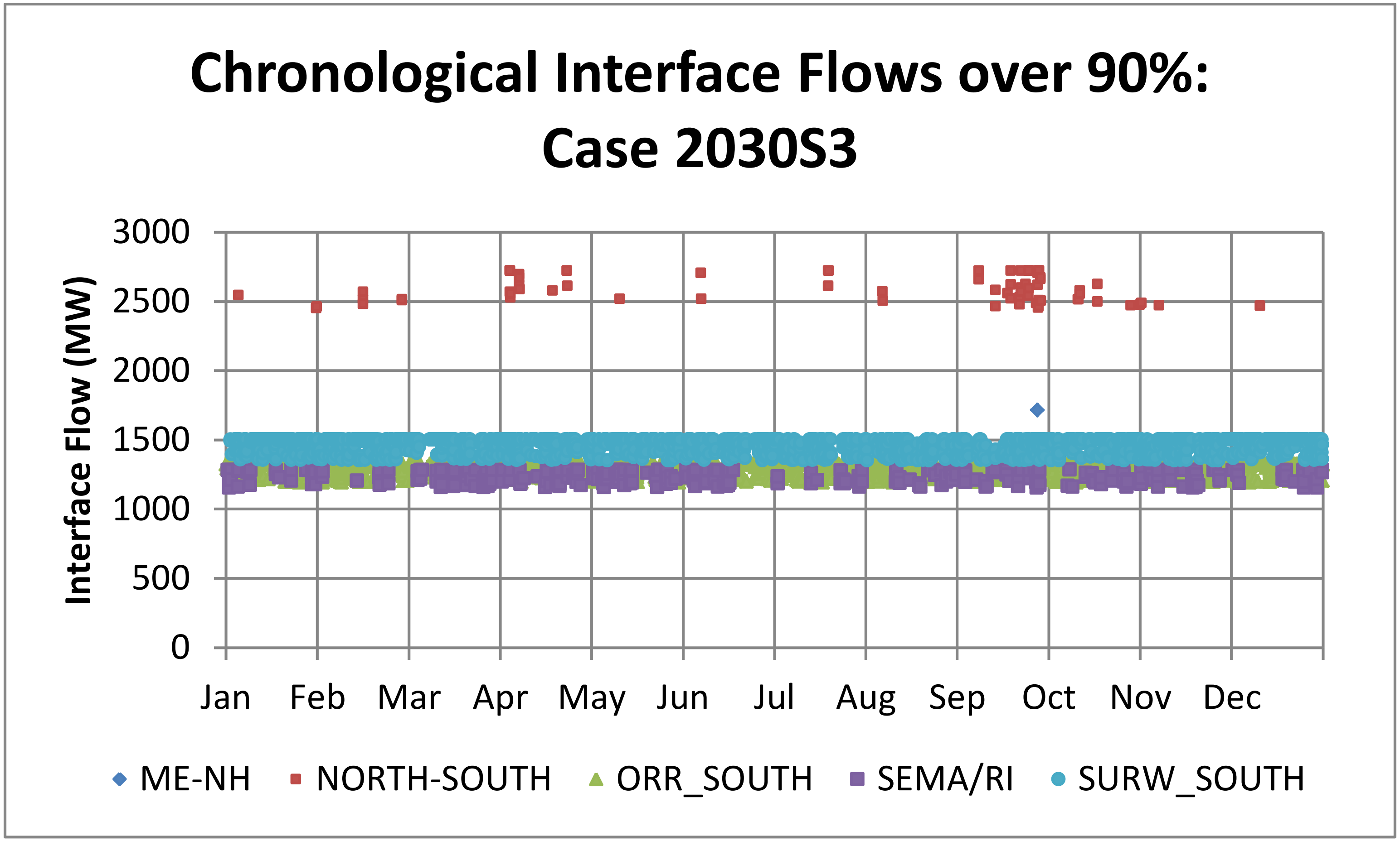
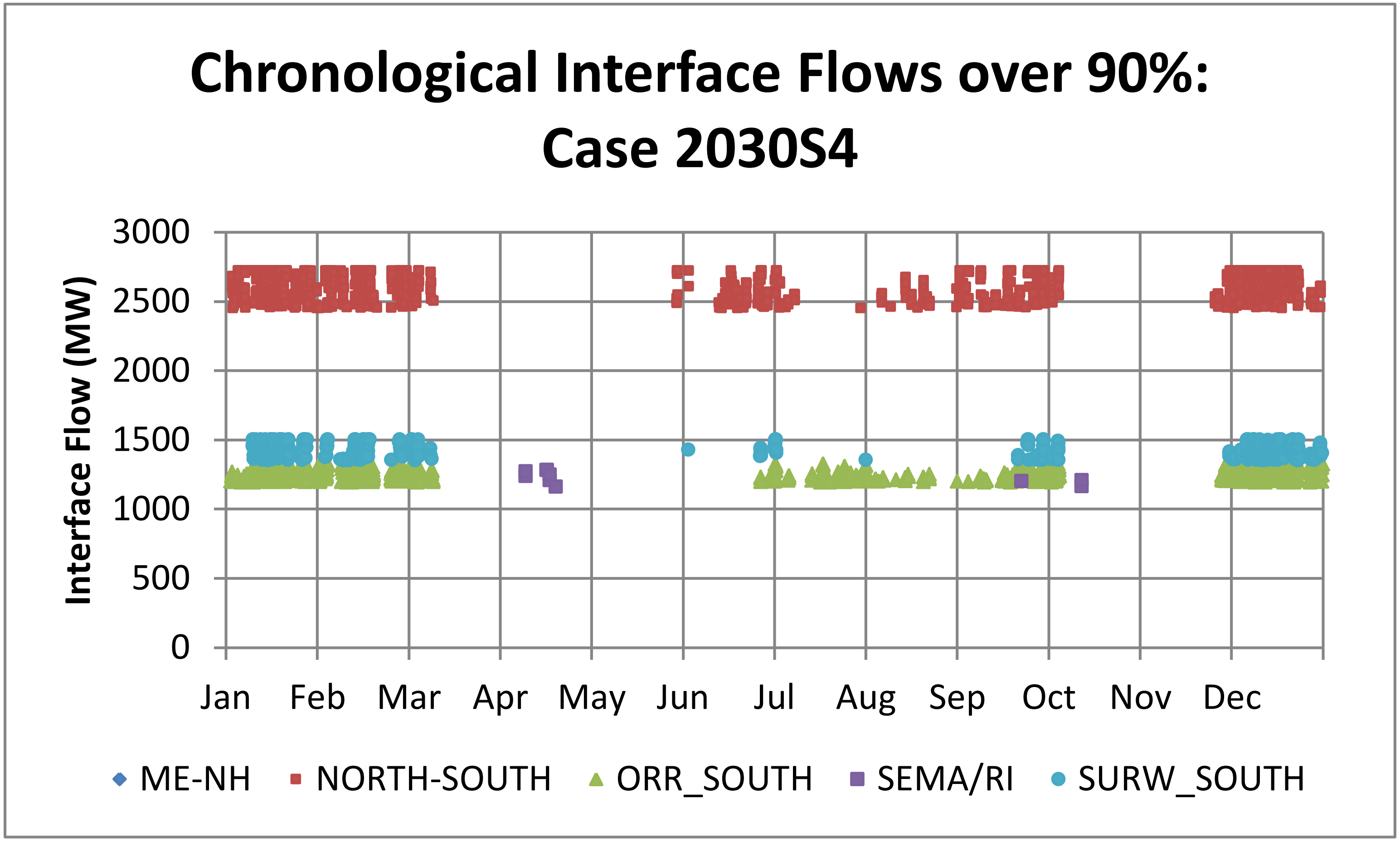


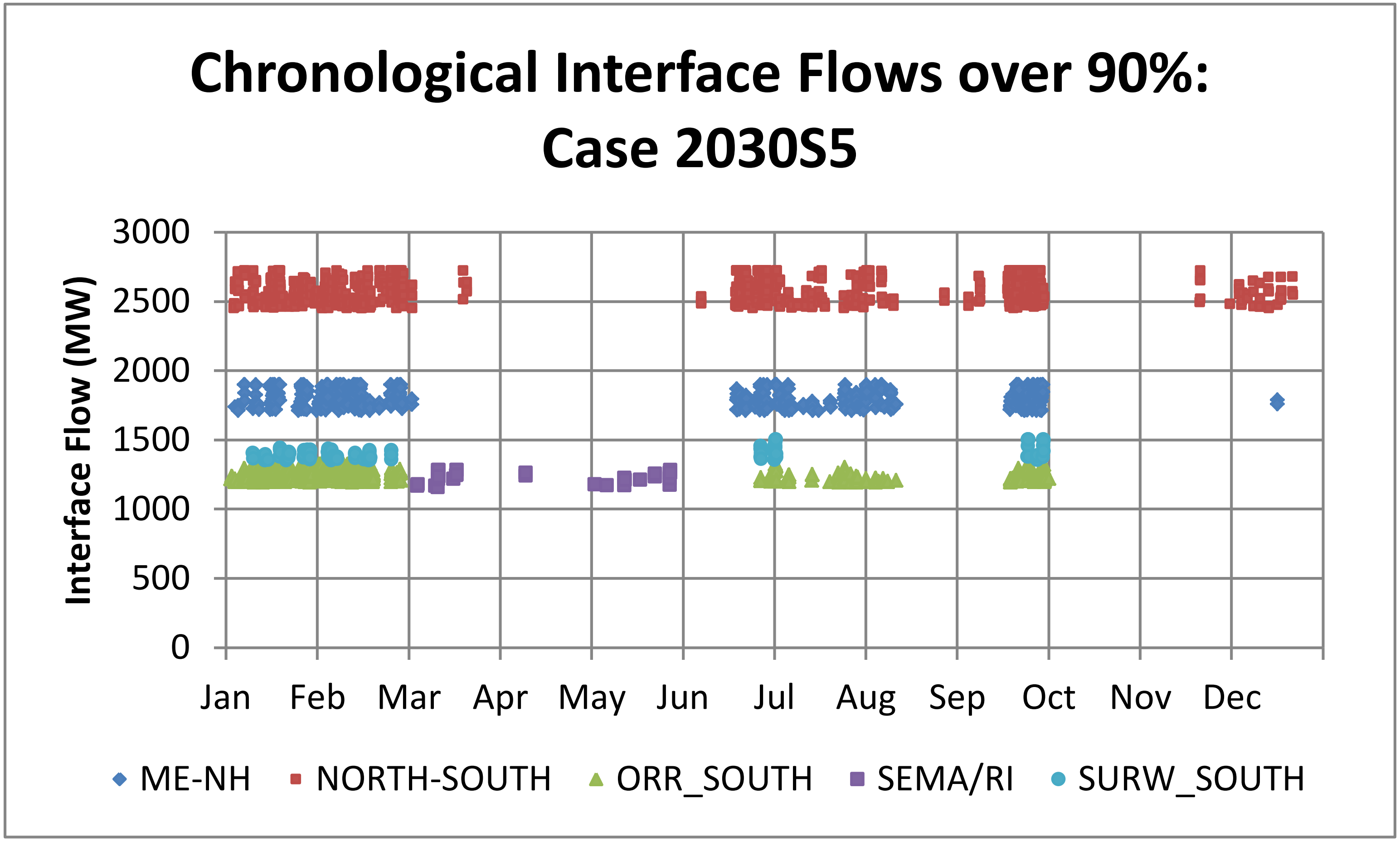
Chronological Interface Flows Exceeds 90% of Rating: 2030 Constrained Scenario 3



Chronological Interface Flows Exceeds 90% of Rating: 2030 Constrained Scenario 4



Chronological Interface Flows Exceeds 90% of Rating: 2030 Constrained Scenario 5

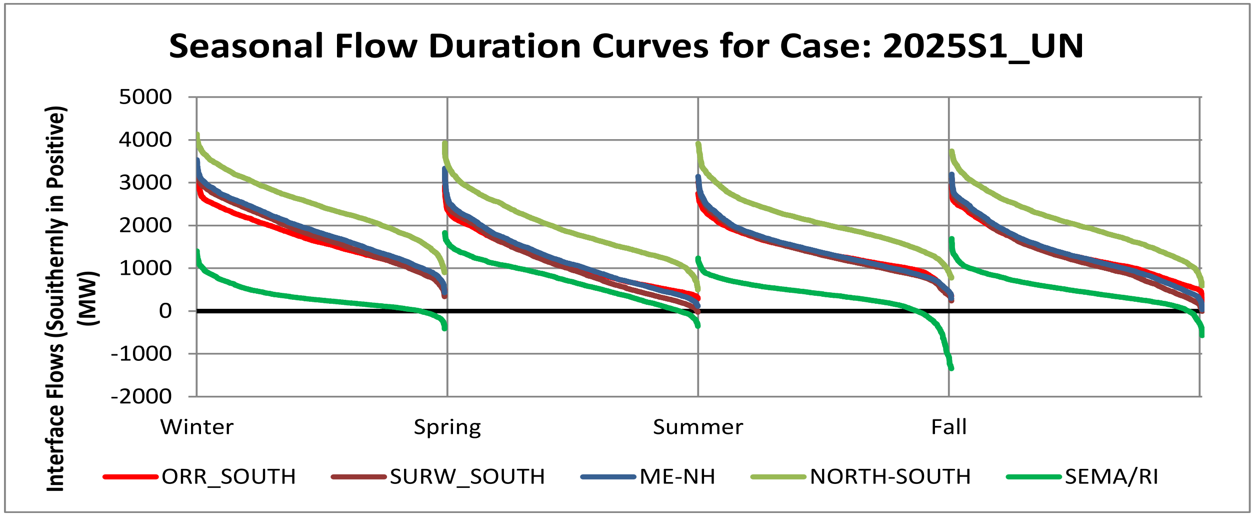


FLOW DURATION CURVES

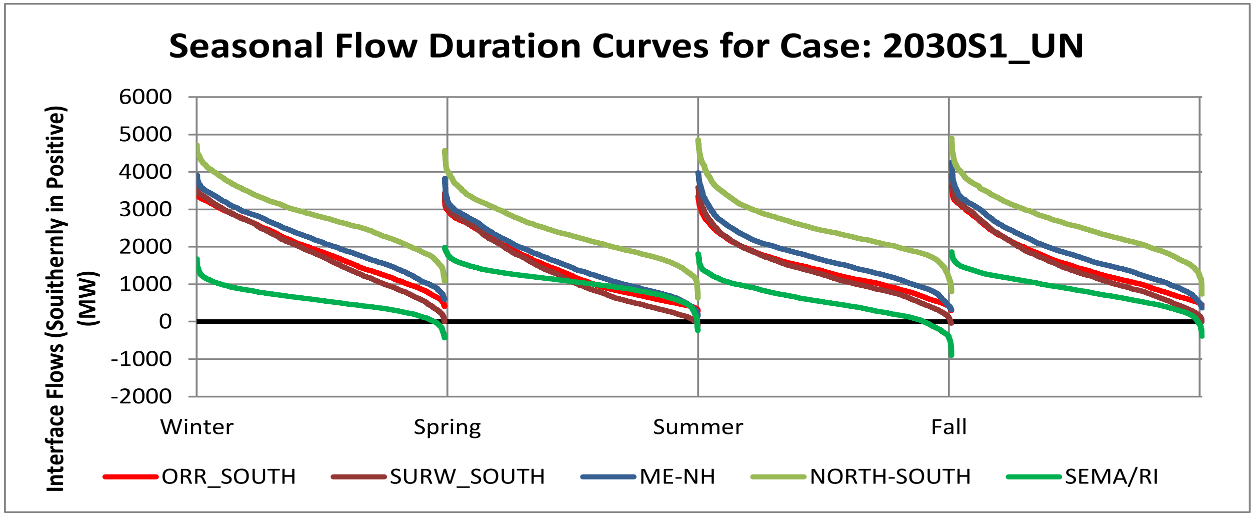
Seasonal

Seasonal Flow Duration Curves - Unconstrained Scenario 1

2025

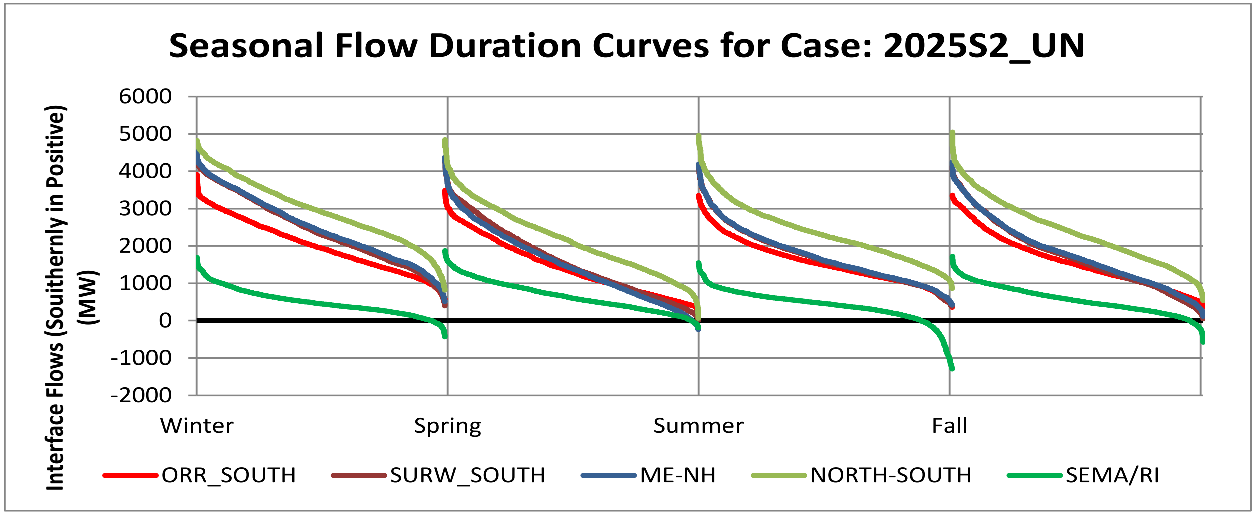


2030



Seasonal Flow Duration Curves - Unconstrained Scenario 2

2025



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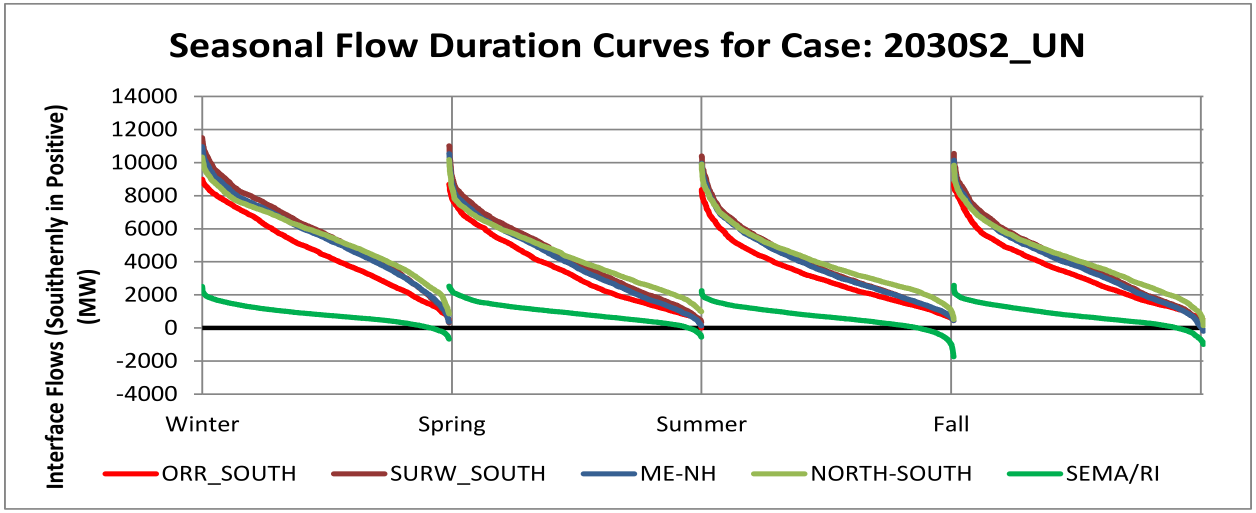
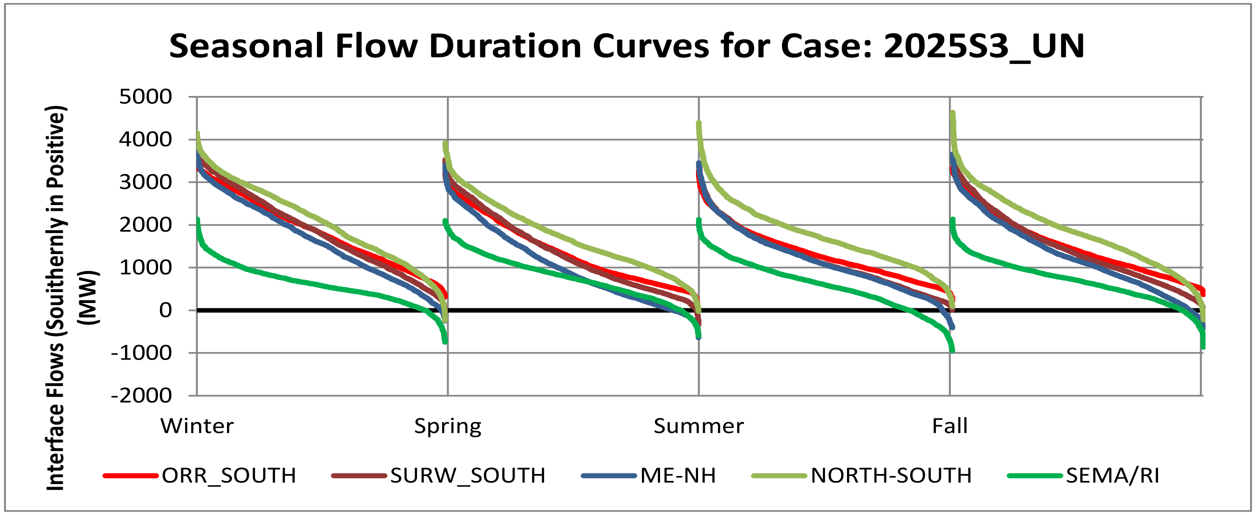


Seasonal Flow Duration Curves - Unconstrained Scenario 3

2025



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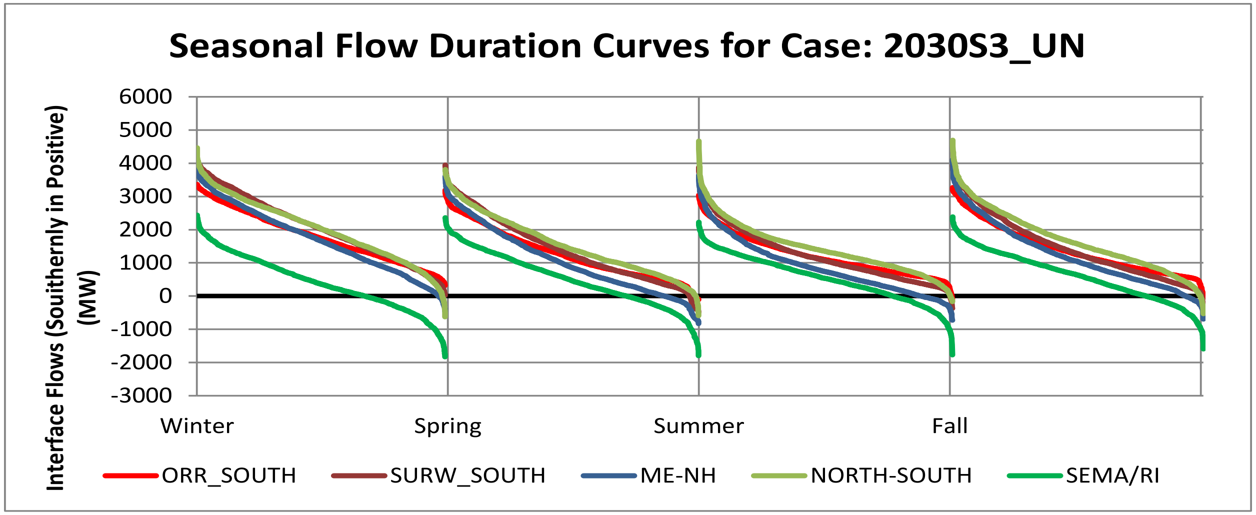
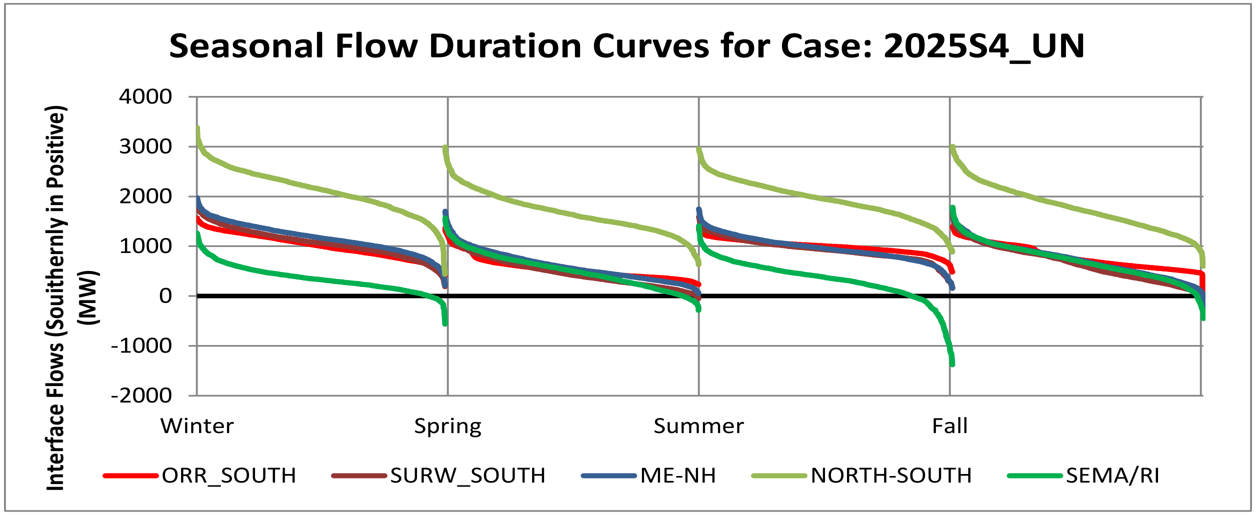


Seasonal Flow Duration Curves - Unconstrained Scenario 4

2025



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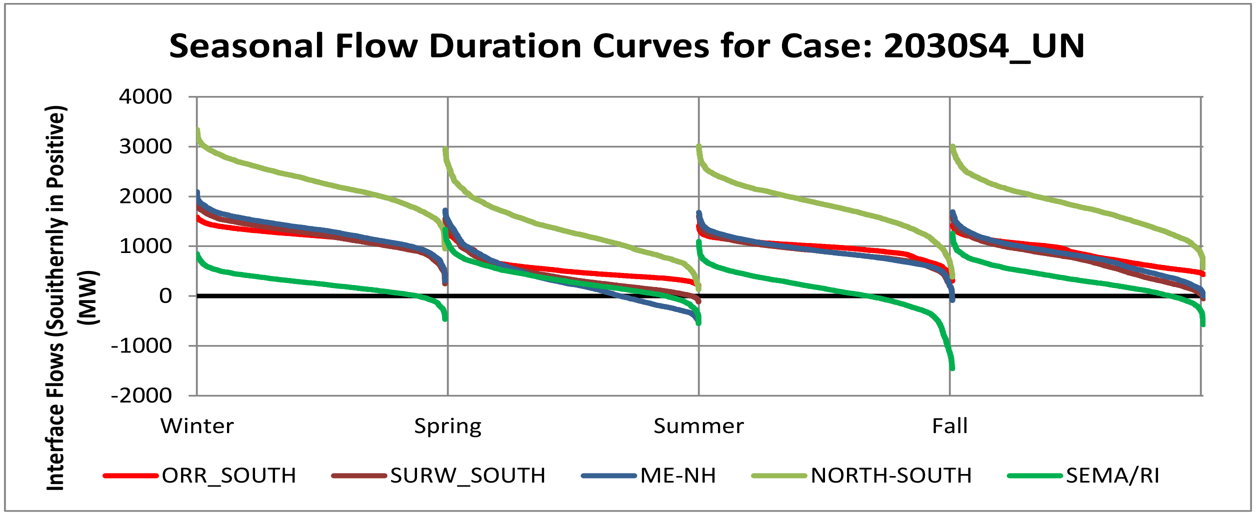
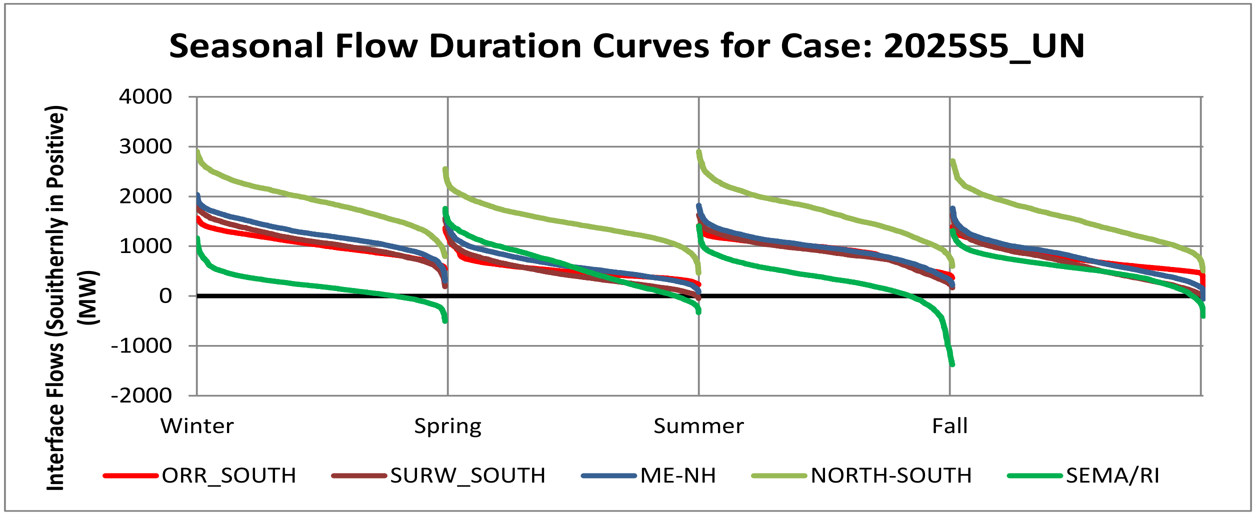


Seasonal Flow Duration Curves - Unconstrained Scenario 5

2025



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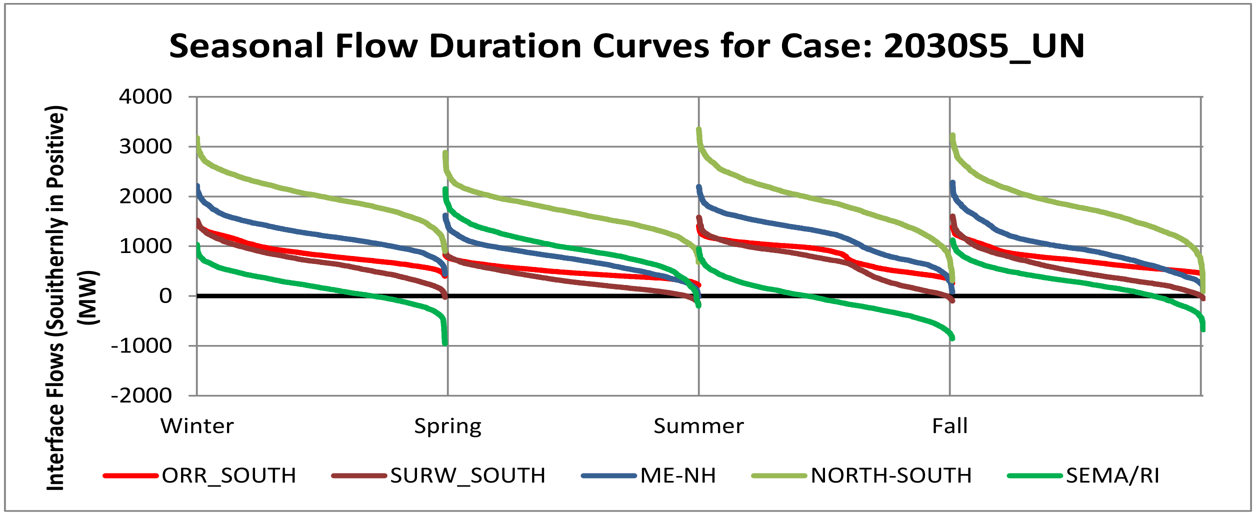
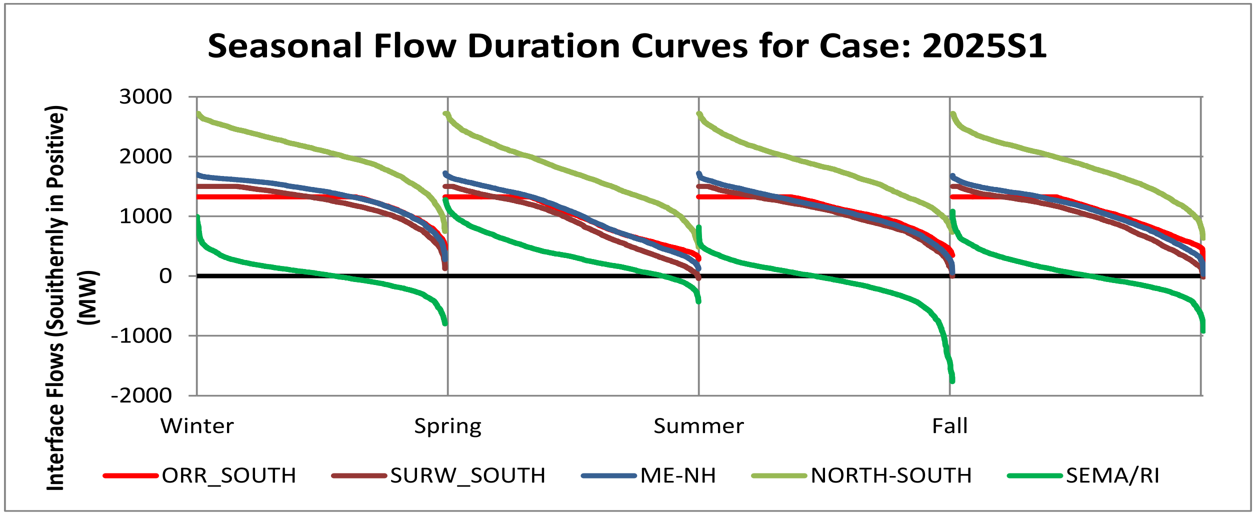
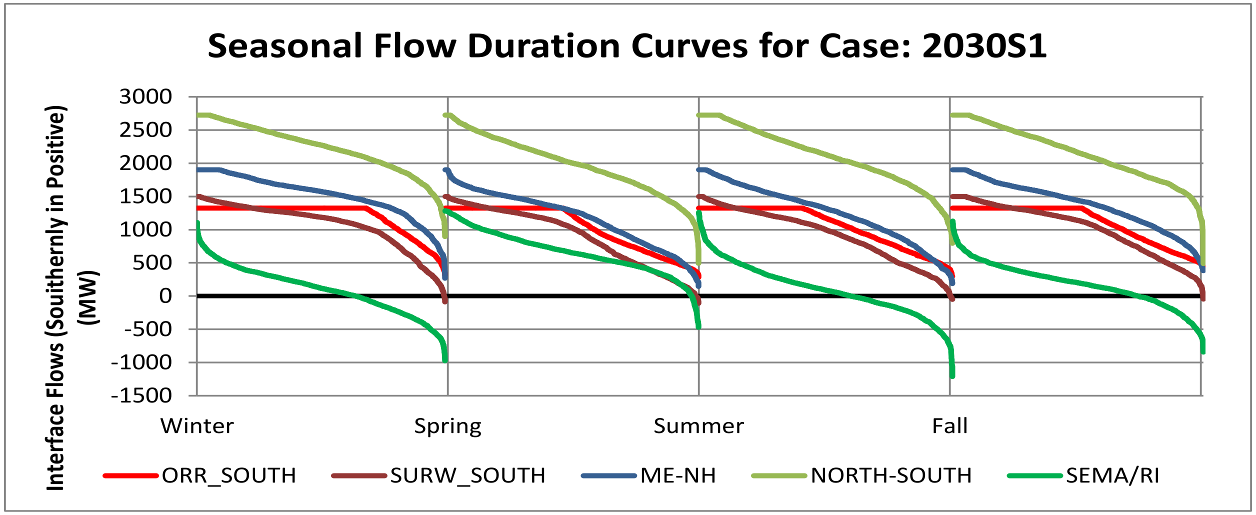


Seasonal Flow Duration Curves – Constrained Scenario 1

2025

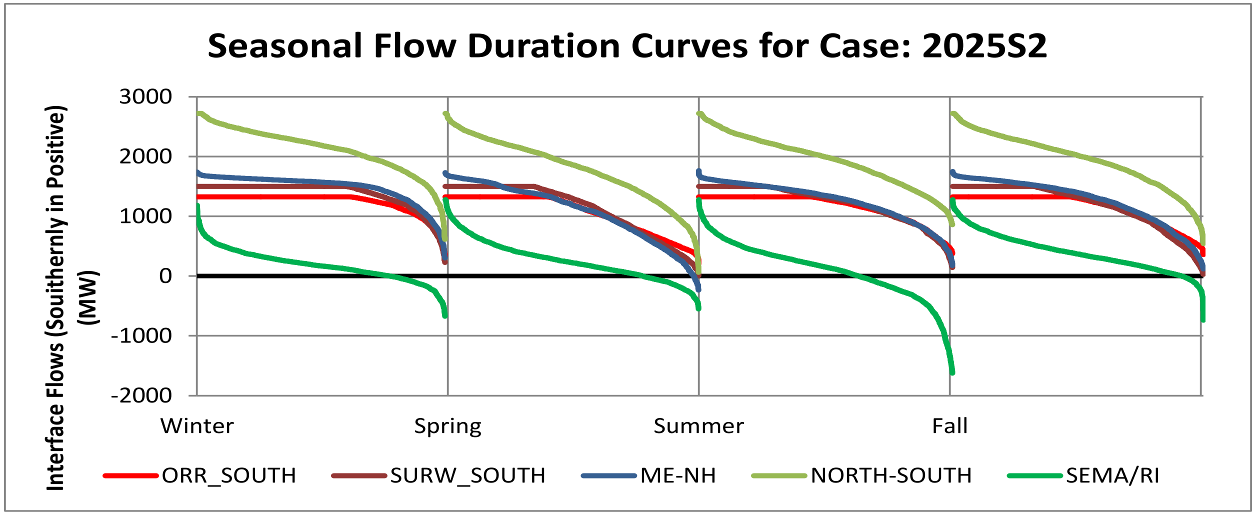


2030



Seasonal Flow Duration Curves – Constrained Scenario 2

2025



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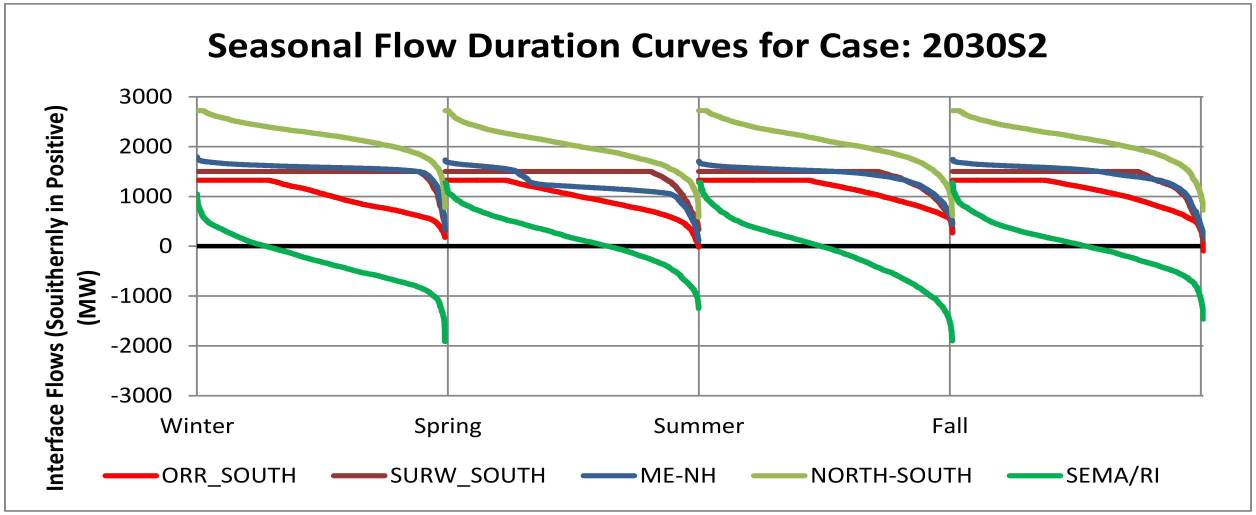
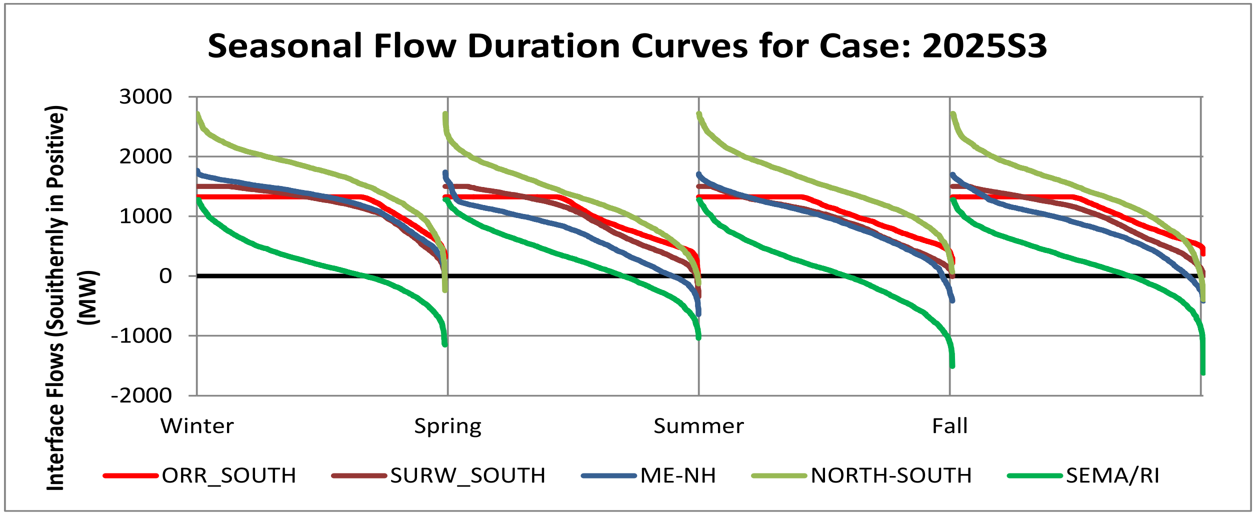


Seasonal Flow Duration Curves – Constrained Scenario 3

2025



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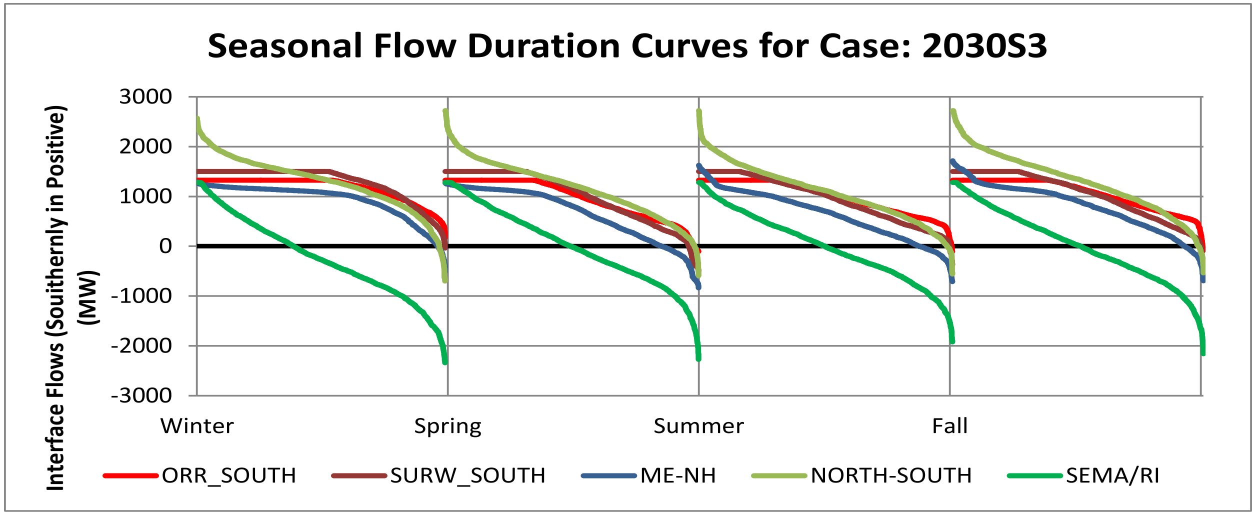
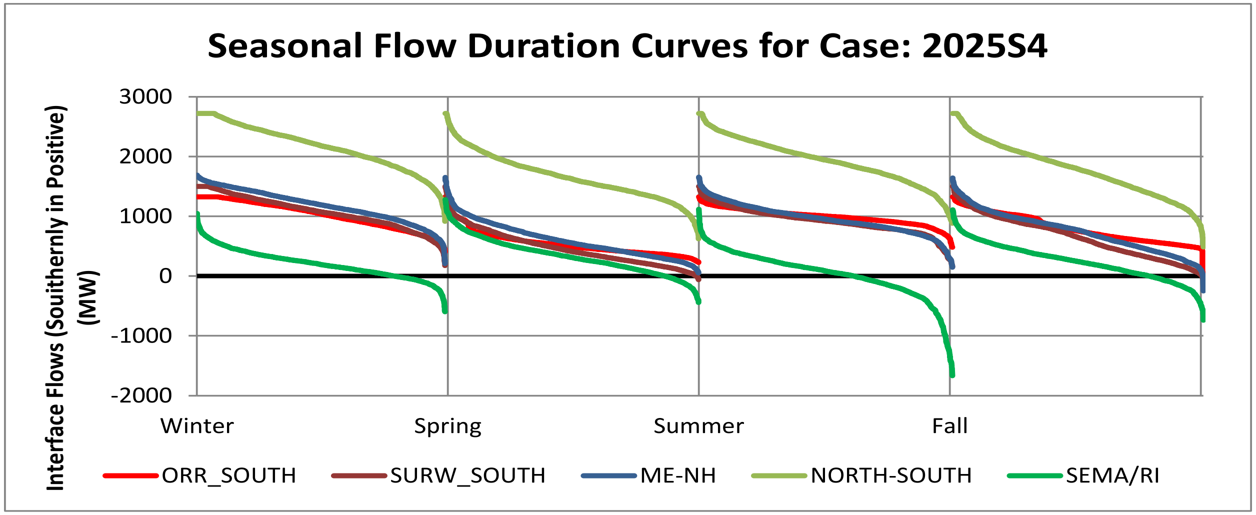
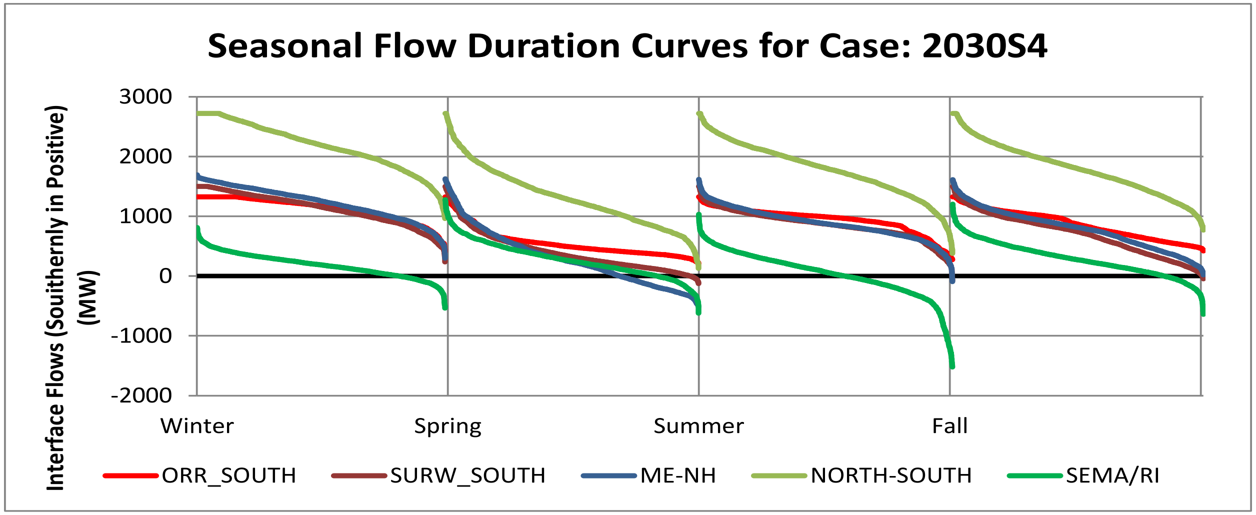


Seasonal Flow Duration Curves – Constrained Scenario 4

2025

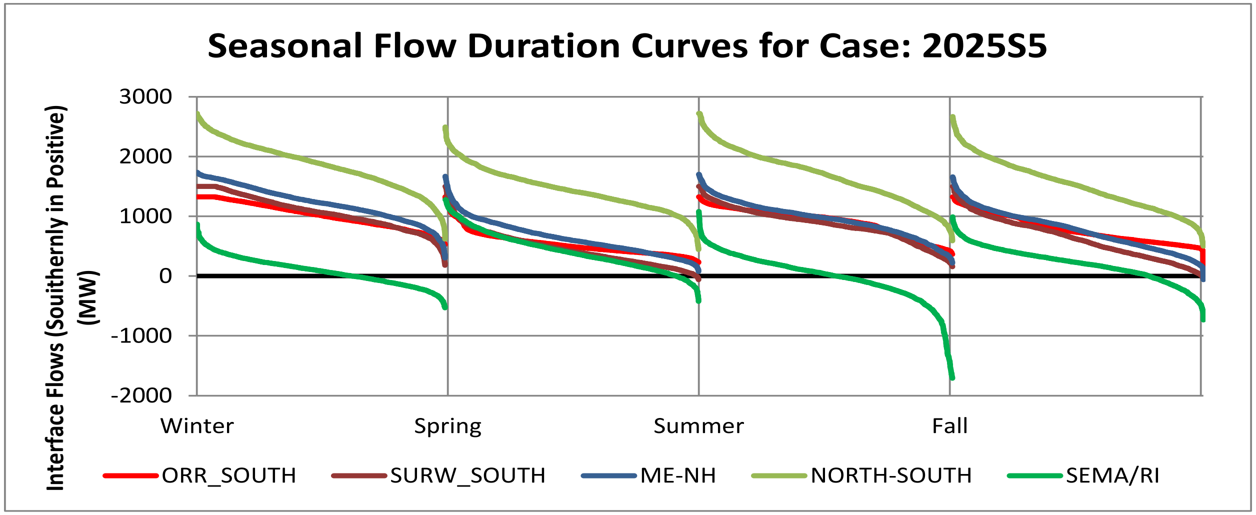


2030



Seasonal Flow Duration Curves – Constrained Scenario 5

2025



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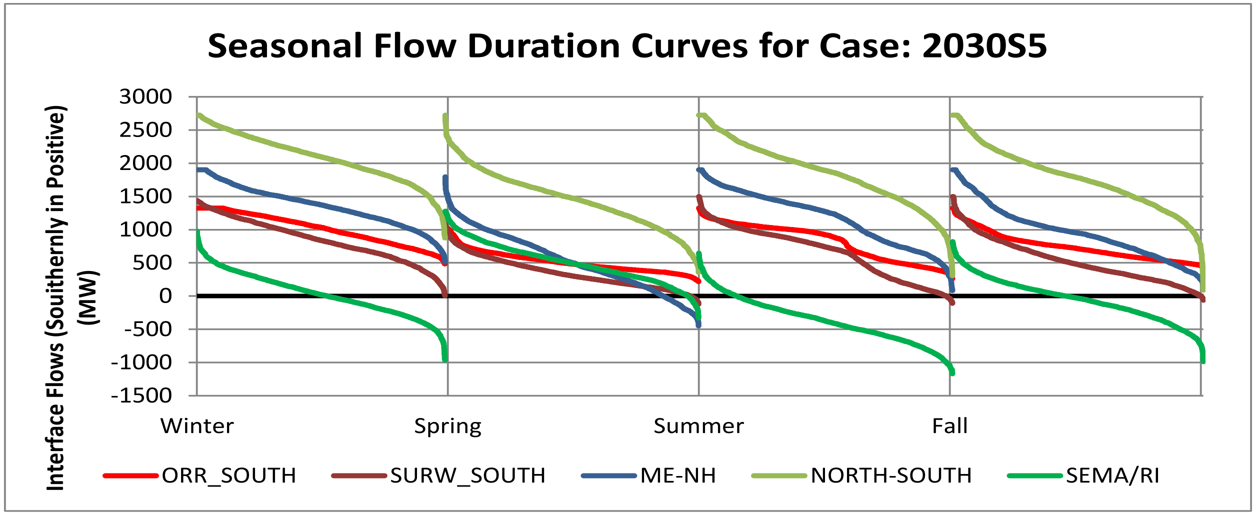
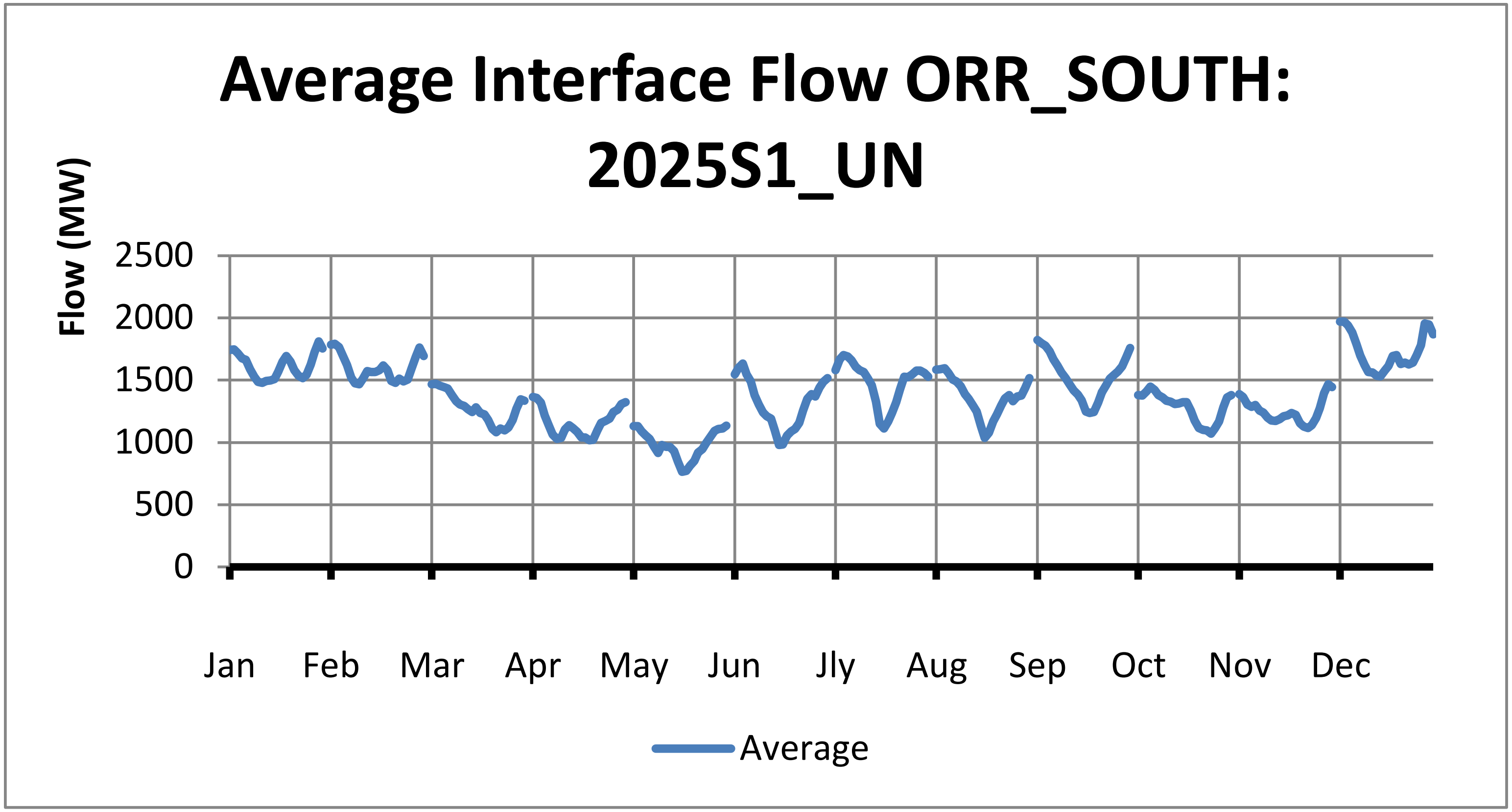


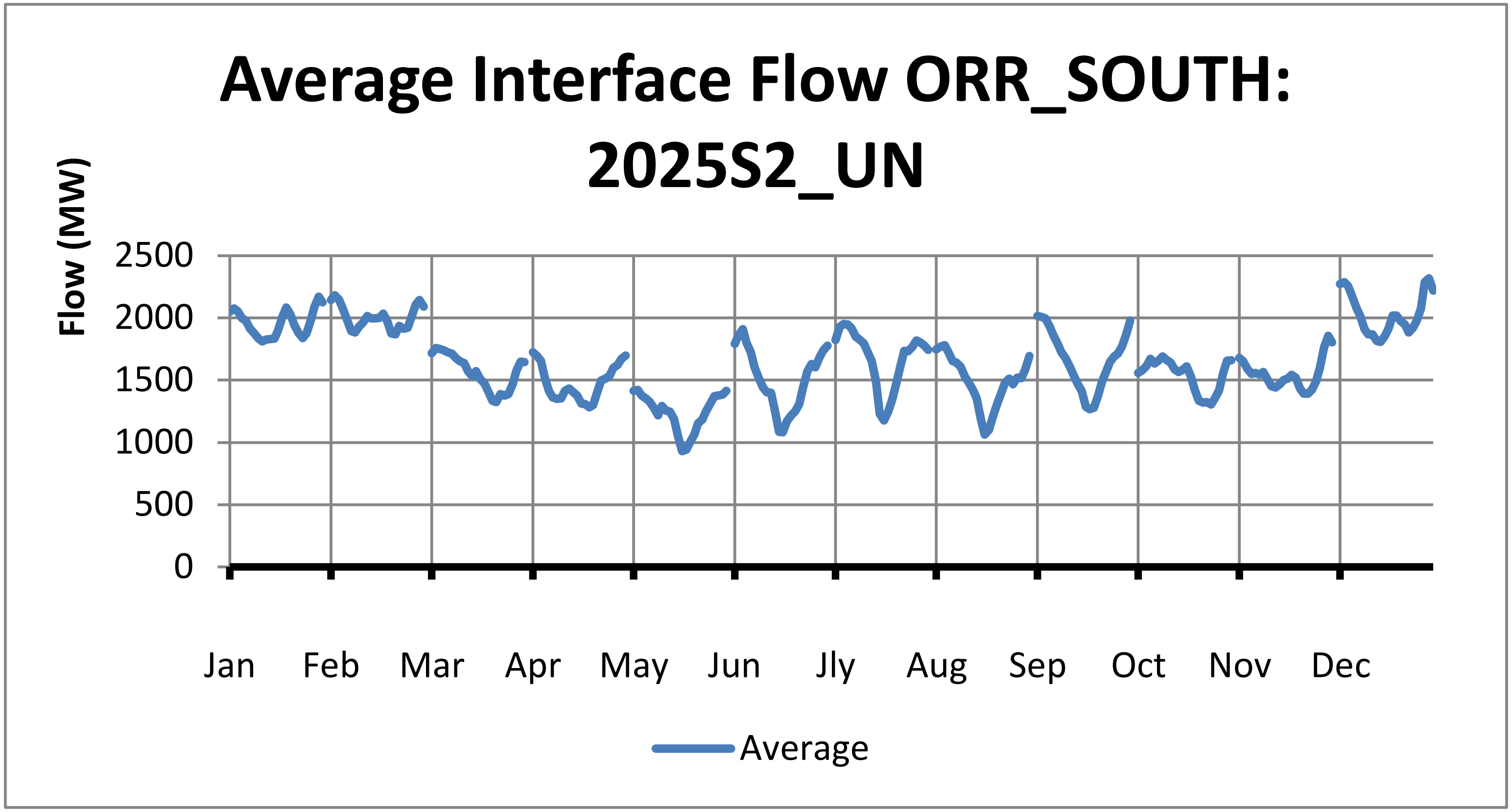
DIURNAL FLOWS ACROSS INTERFACES 2025 AND 2030

Orrington South Interface

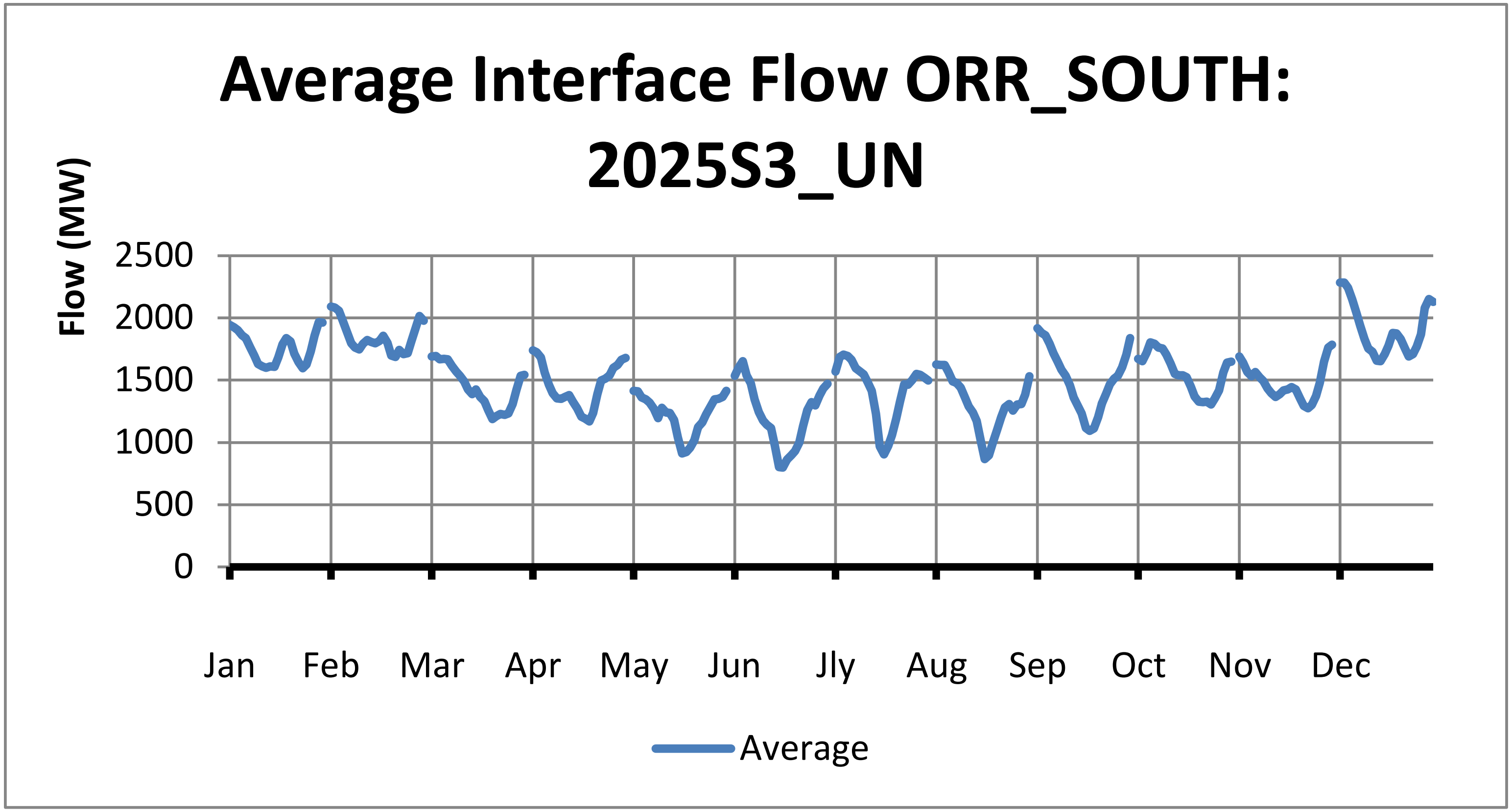
Diurnal Interface Flow – Orrington South 2025 Unconstrained Scenario 1



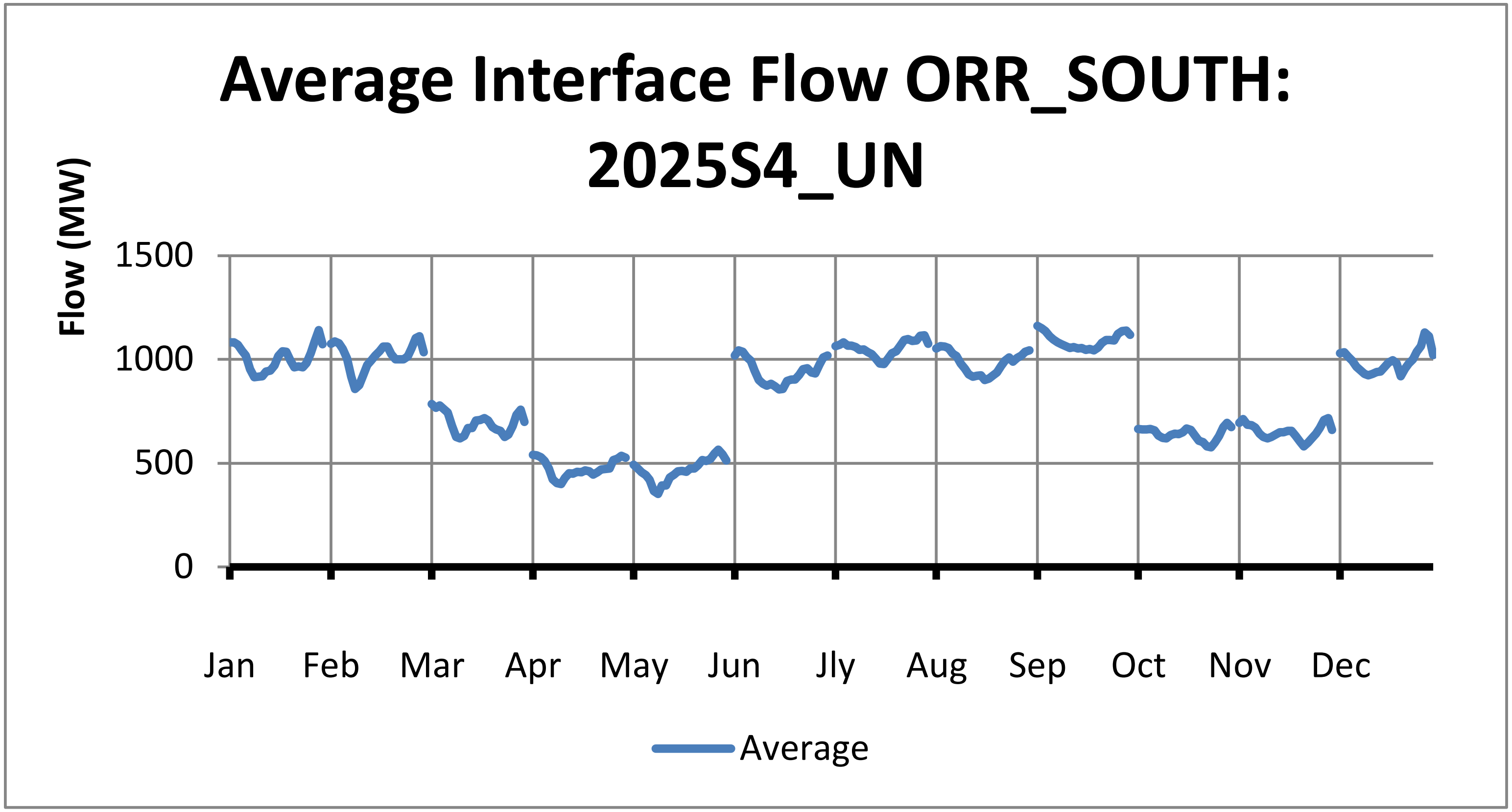
Diurnal Interface Flow – Orrington South 2025 Unconstrained Scenario 2



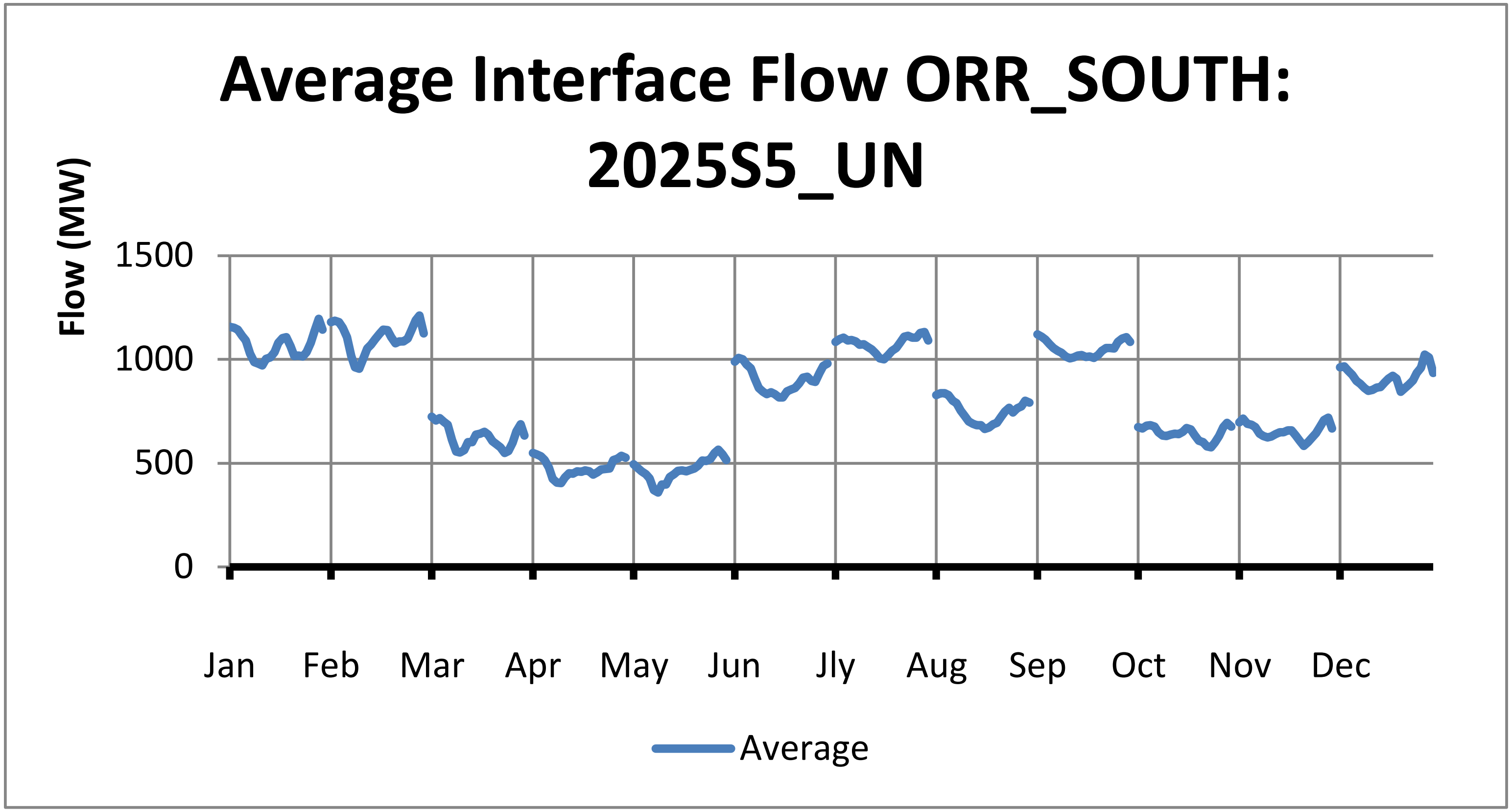
Diurnal Interface Flow – Orrington South 2025 Unconstrained Scenario 3



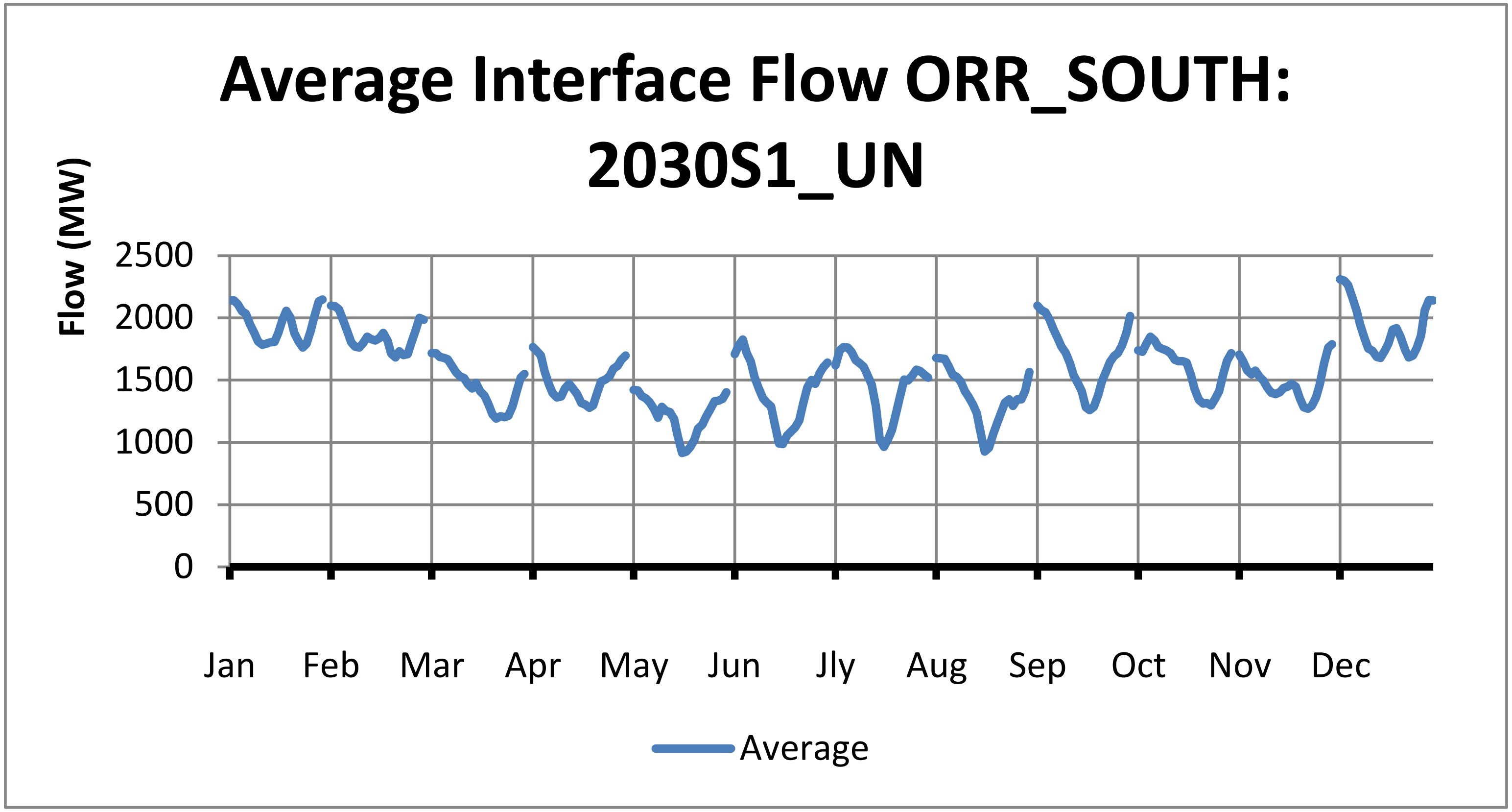
Diurnal Interface Flow – Orrington South 2025 Unconstrained Scenario 4



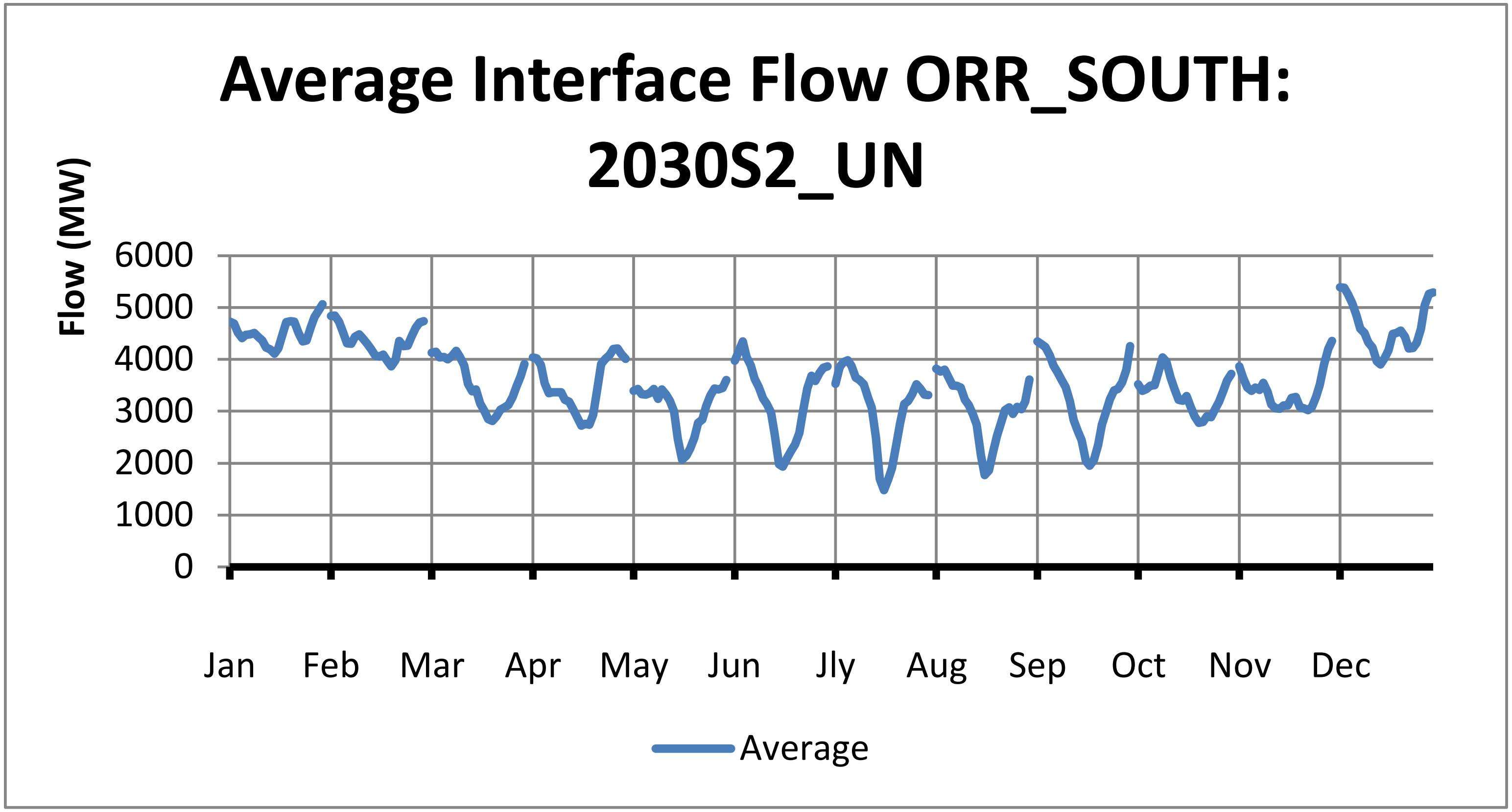
Diurnal Interface Flow – Orrington South 2025 Unconstrained Scenario 5



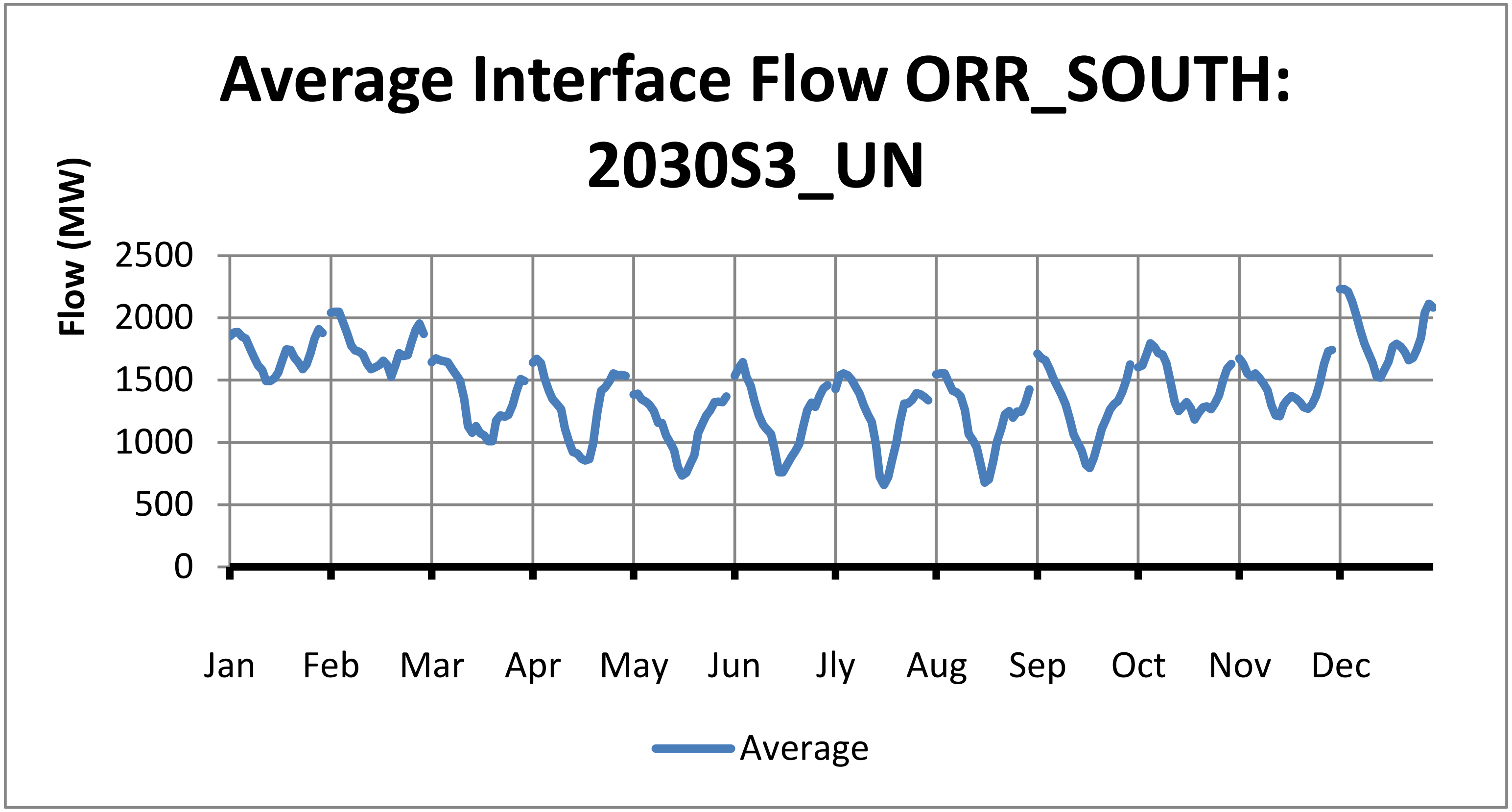
Diurnal Interface Flow – Orrington South 2030 Unconstrained Scenario 1



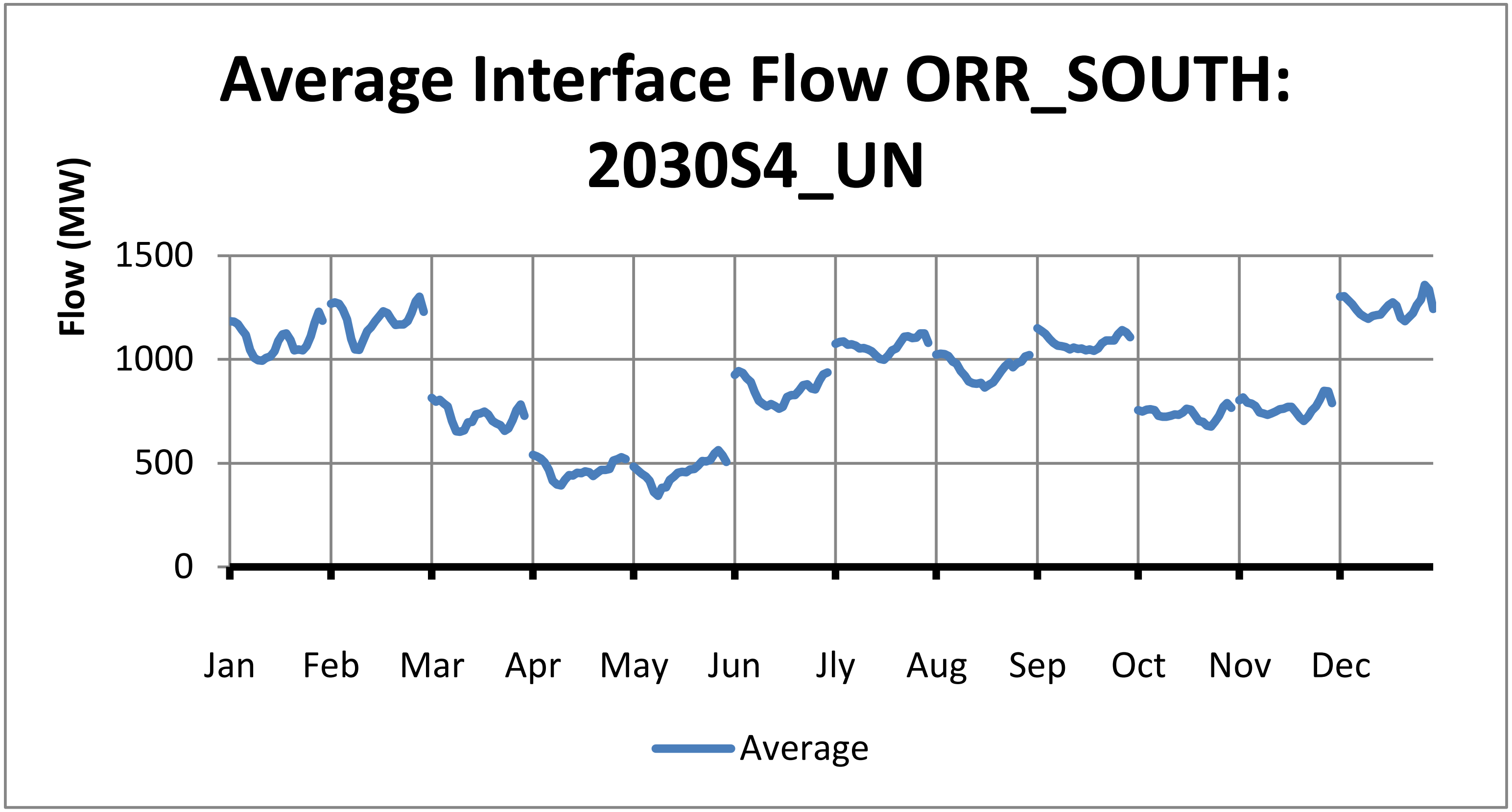
Diurnal Interface Flow – Orrington South 2030 Unconstrained Scenario 2



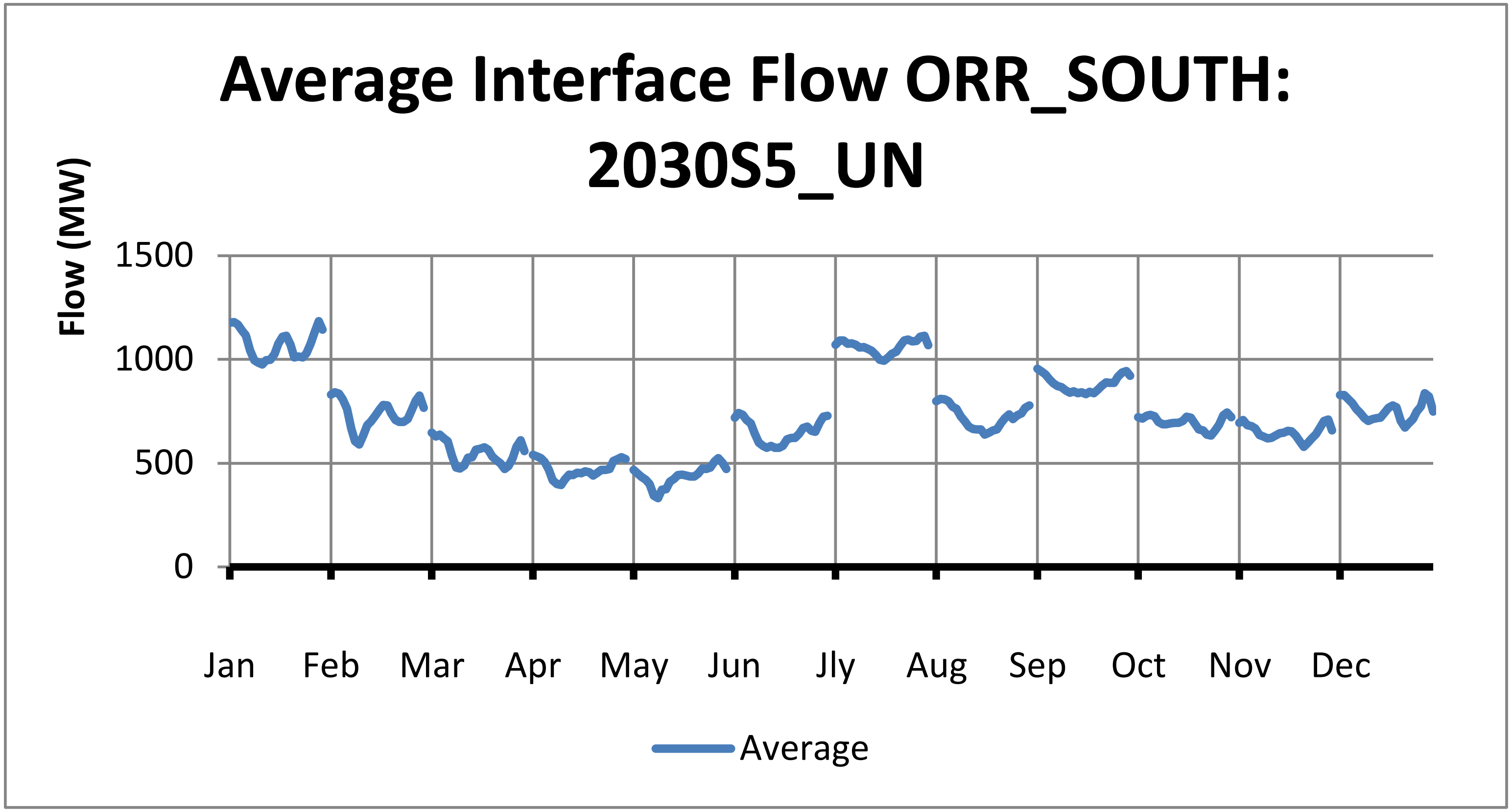
Diurnal Interface Flow – Orrington South 2030 Unconstrained Scenario 3



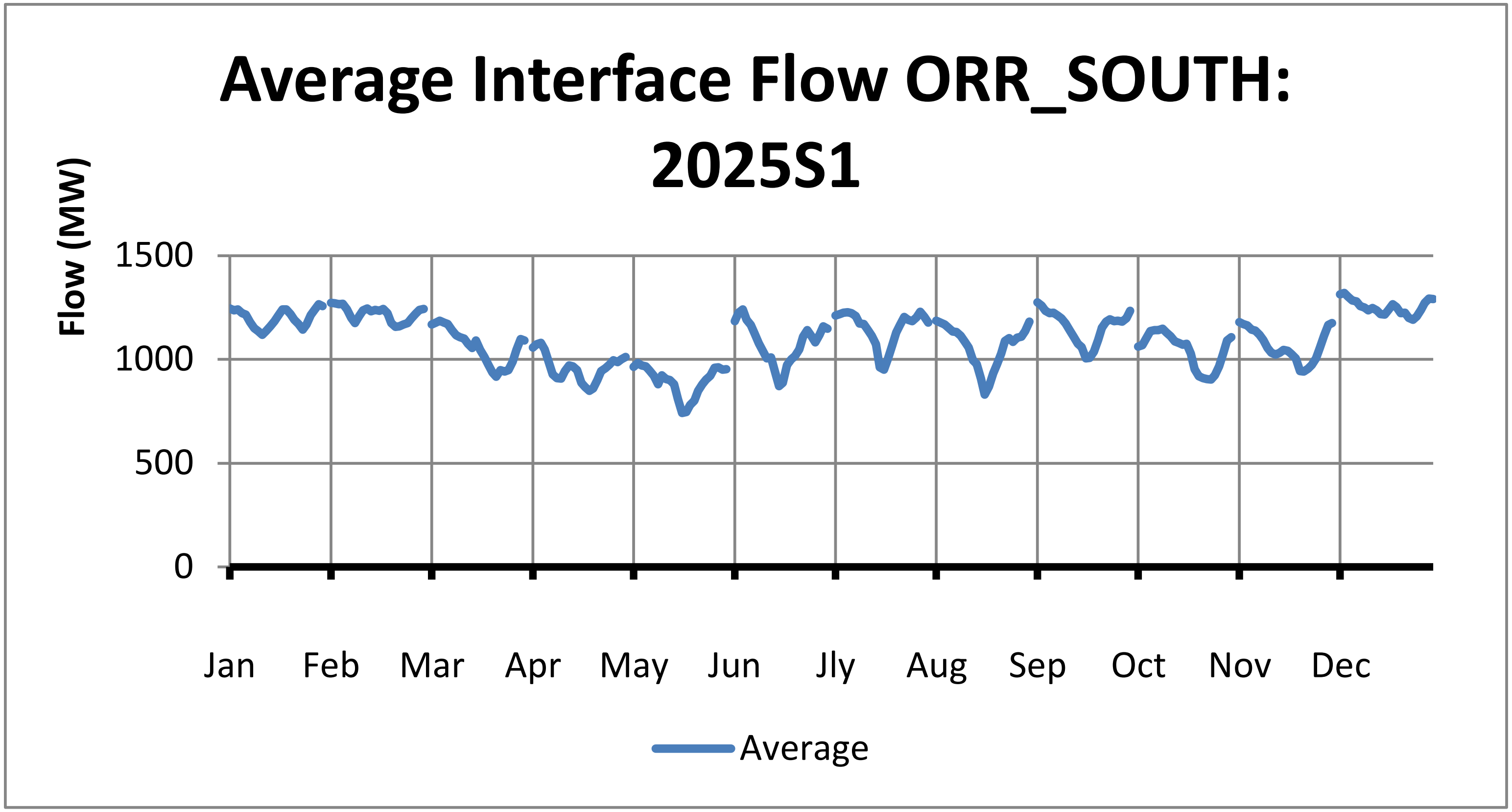
Diurnal Interface Flow – Orrington South 2030 Unconstrained Scenario 4



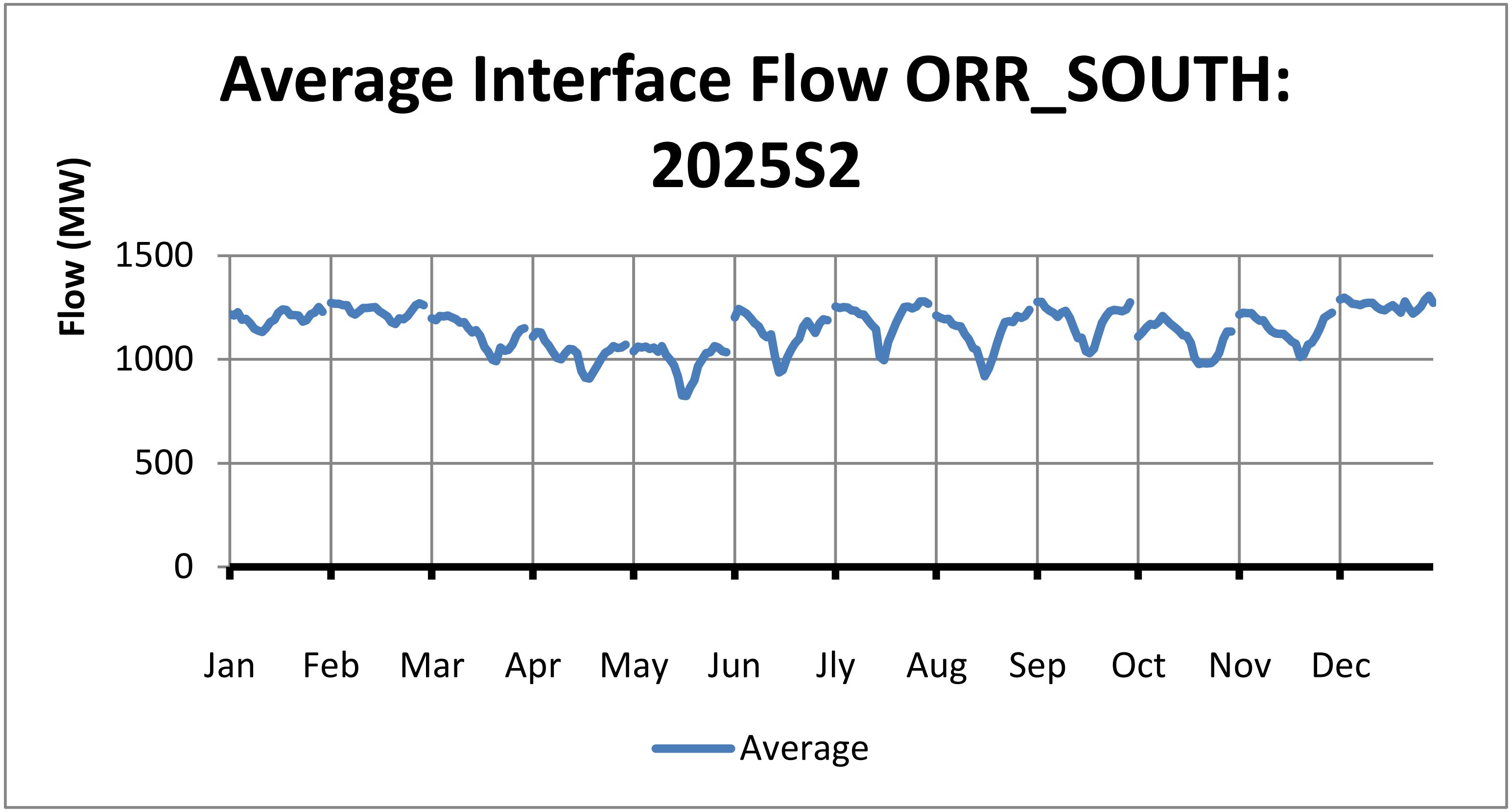
Diurnal Interface Flow – Orrington South 2030 Unconstrained Scenario 5



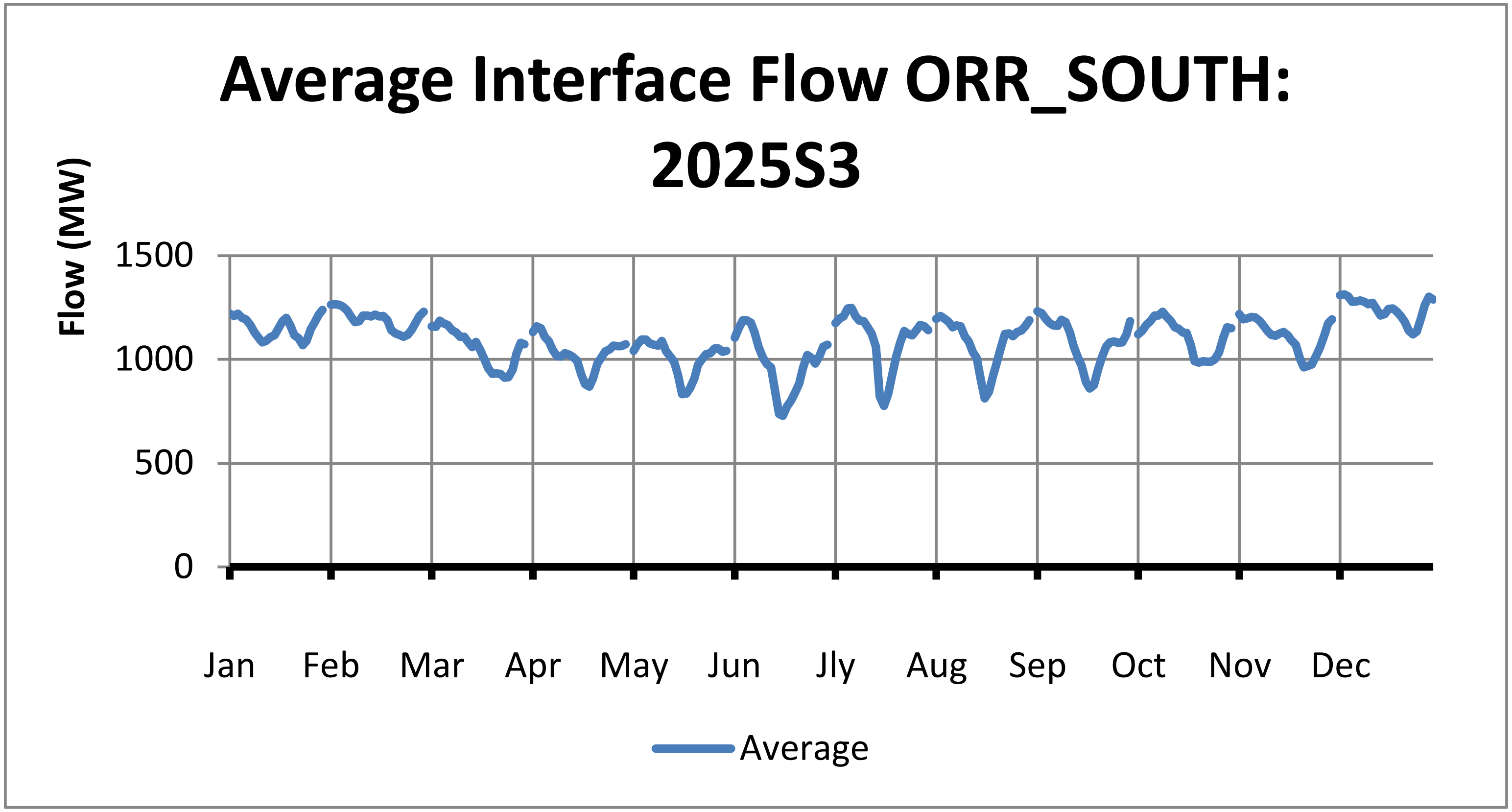
Diurnal Interface Flow – Orrington South 2025 Scenario 1



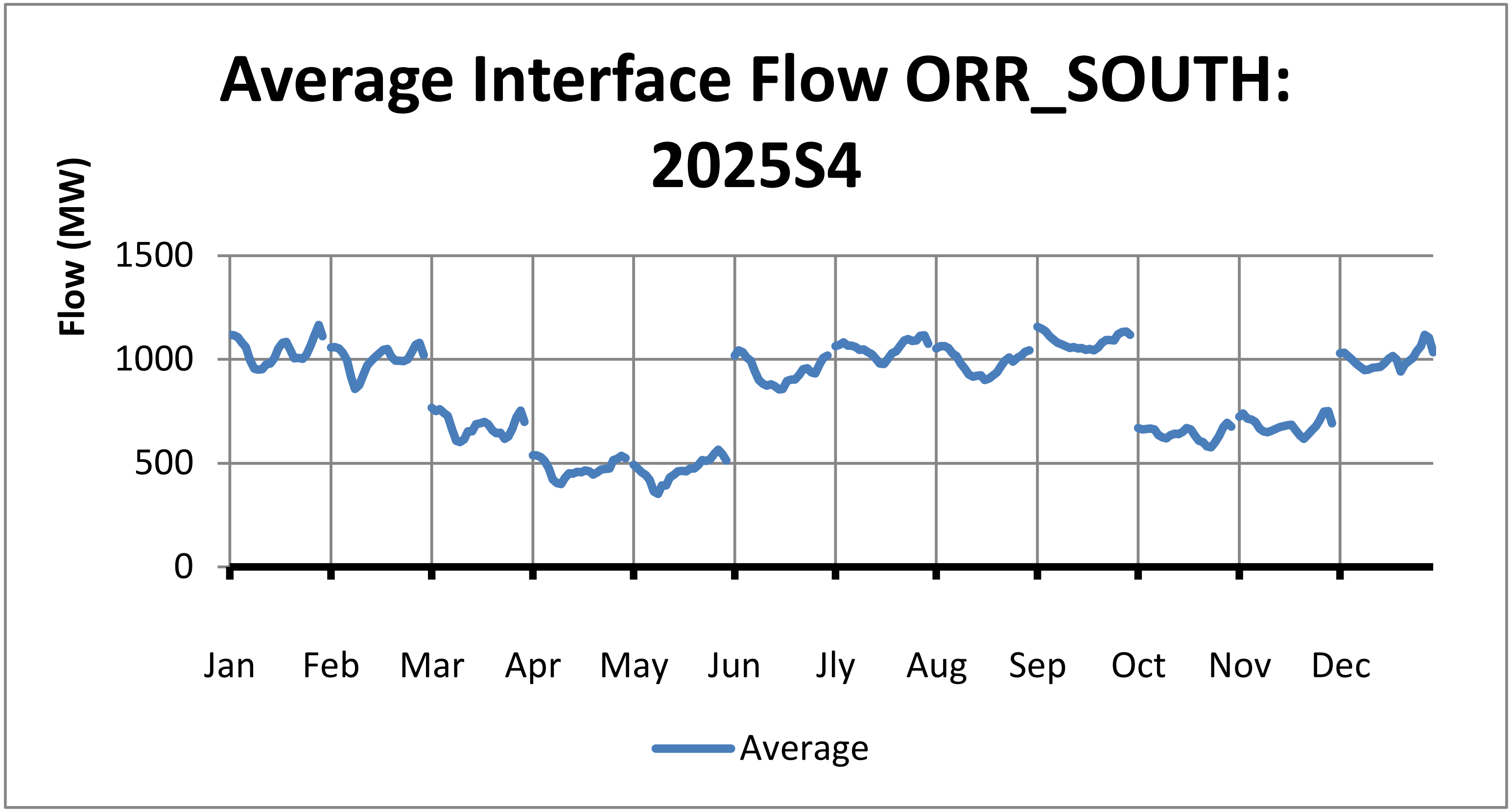
Diurnal Interface Flow – Orrington South 2025 Scenario 2



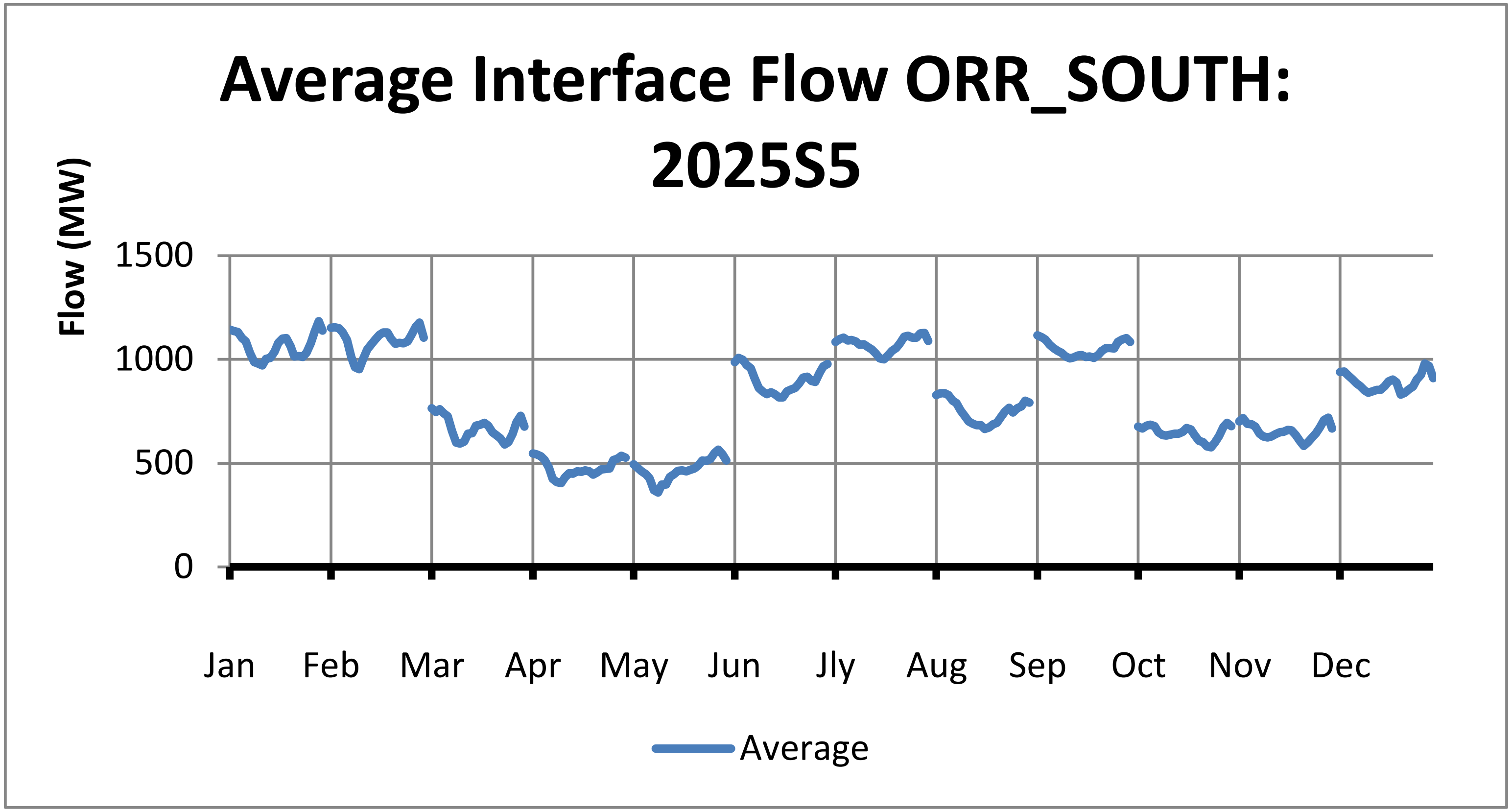
Diurnal Interface Flow – Orrington South 2025 Scenario 3



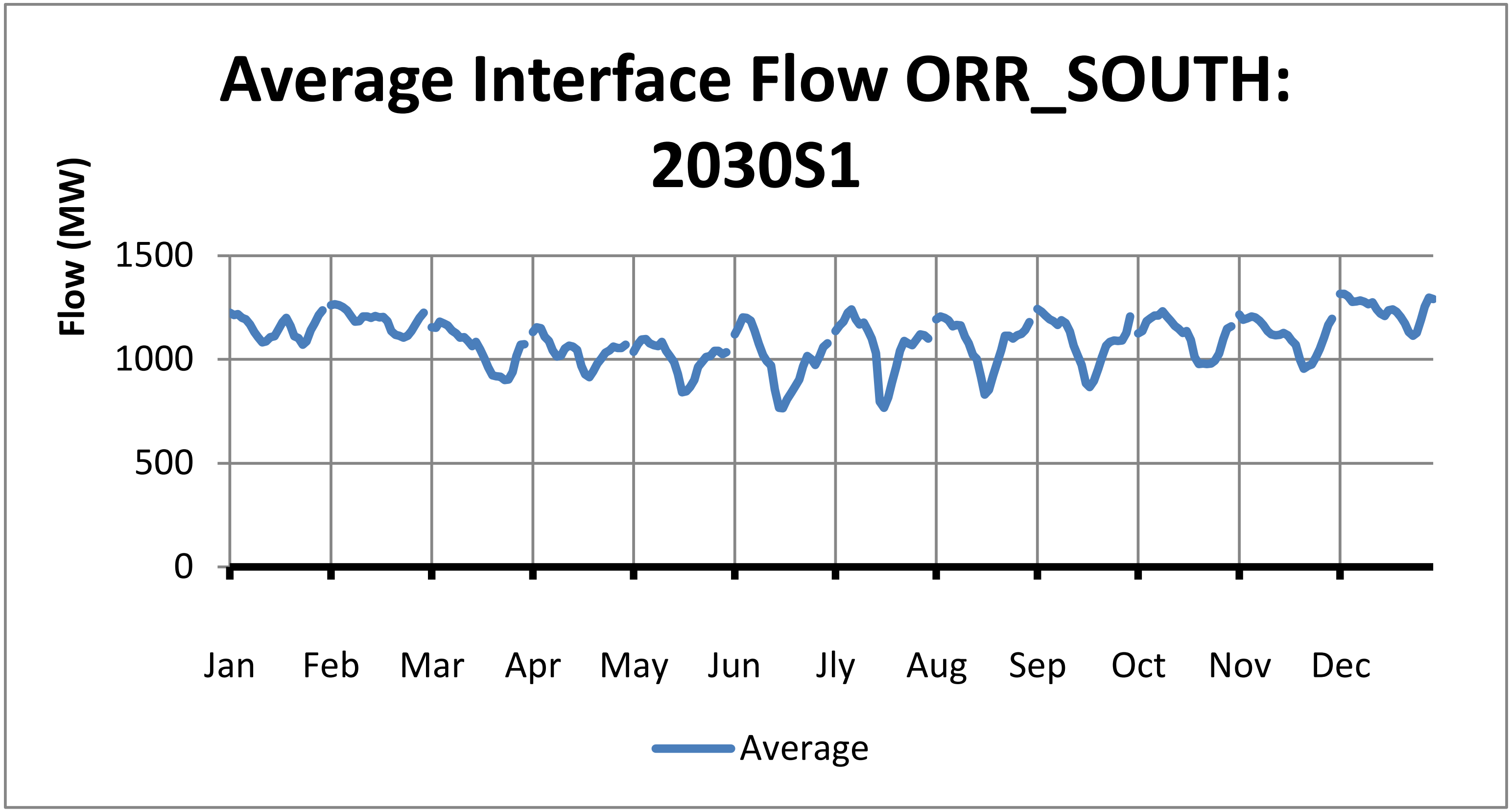
Diurnal Interface Flow – Orrington South 2025 Scenario 4



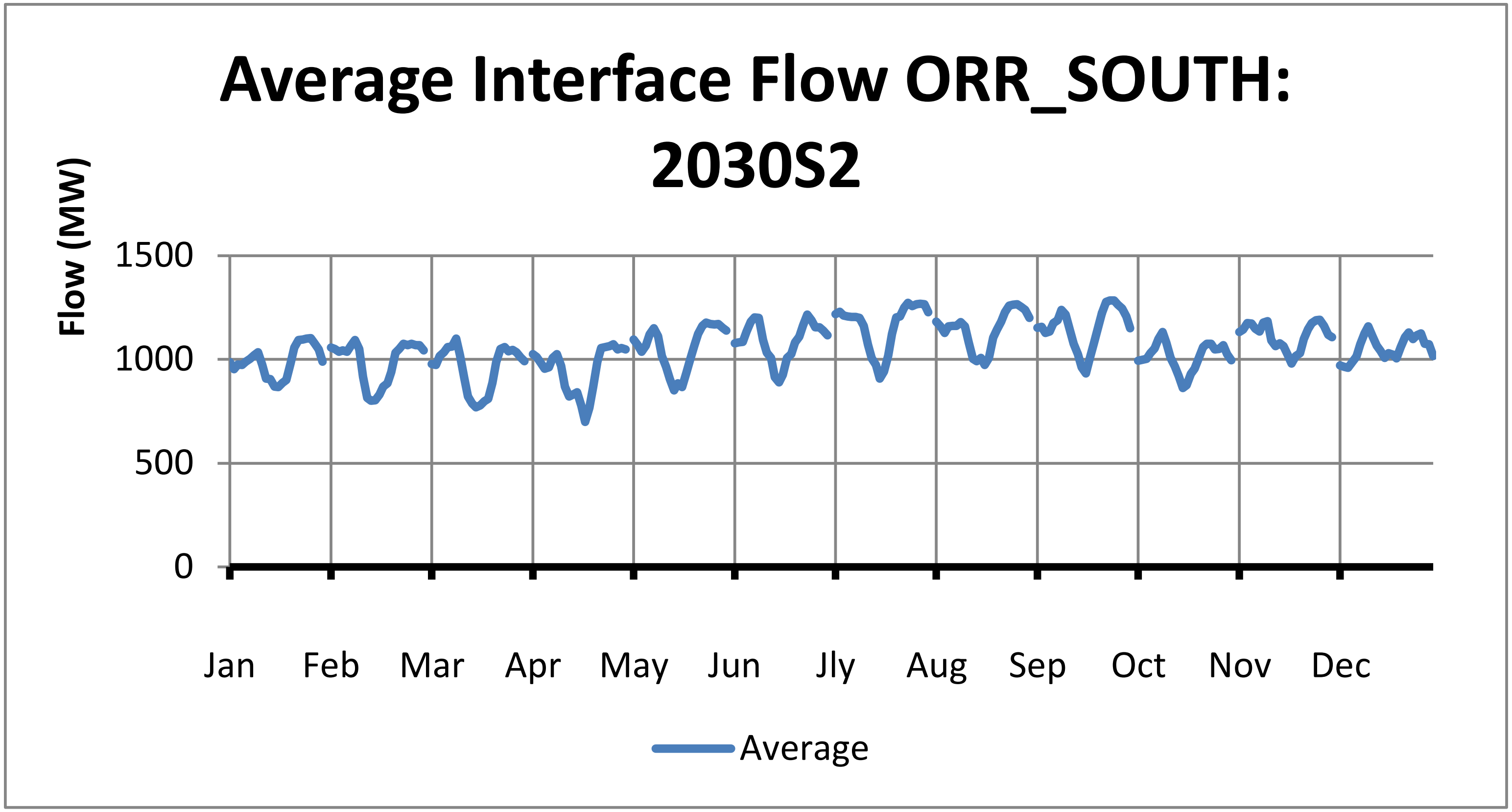
Diurnal Interface Flow – Orrington South 2025 Scenario 5



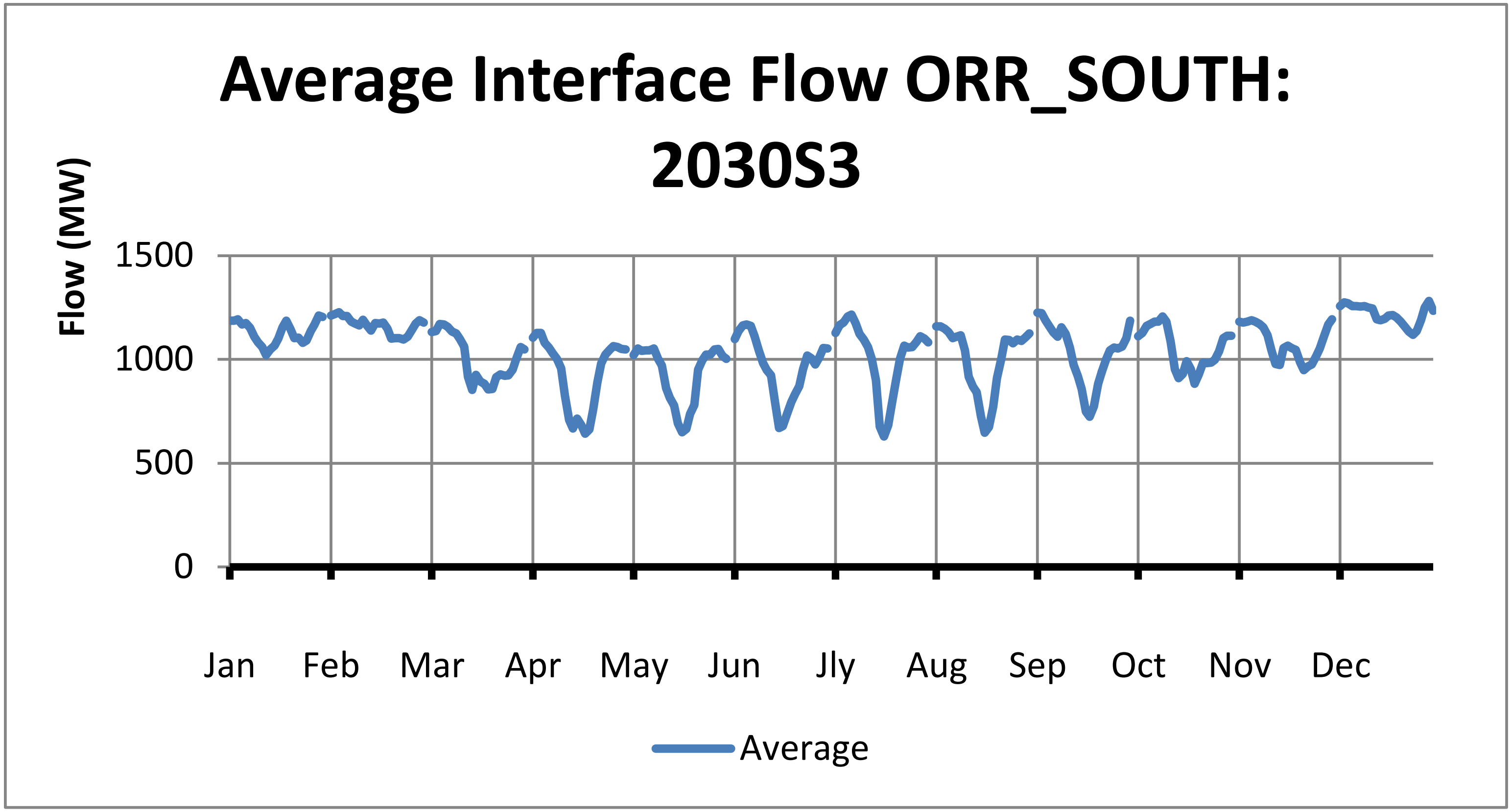
Diurnal Interface Flow – Orrington South 2030 Scenario 1



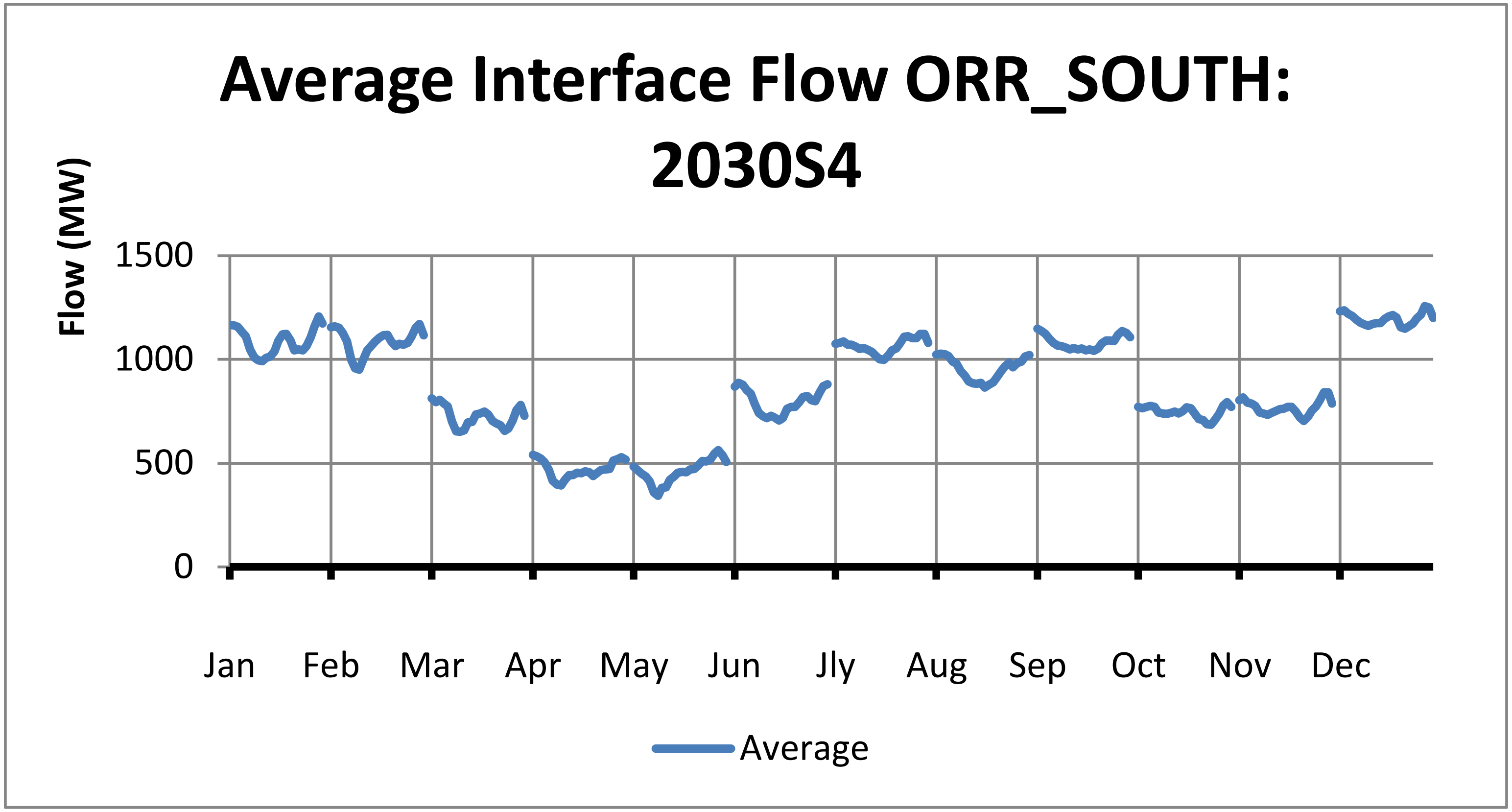
Diurnal Interface Flow – Orrington South 2030 Scenario 2



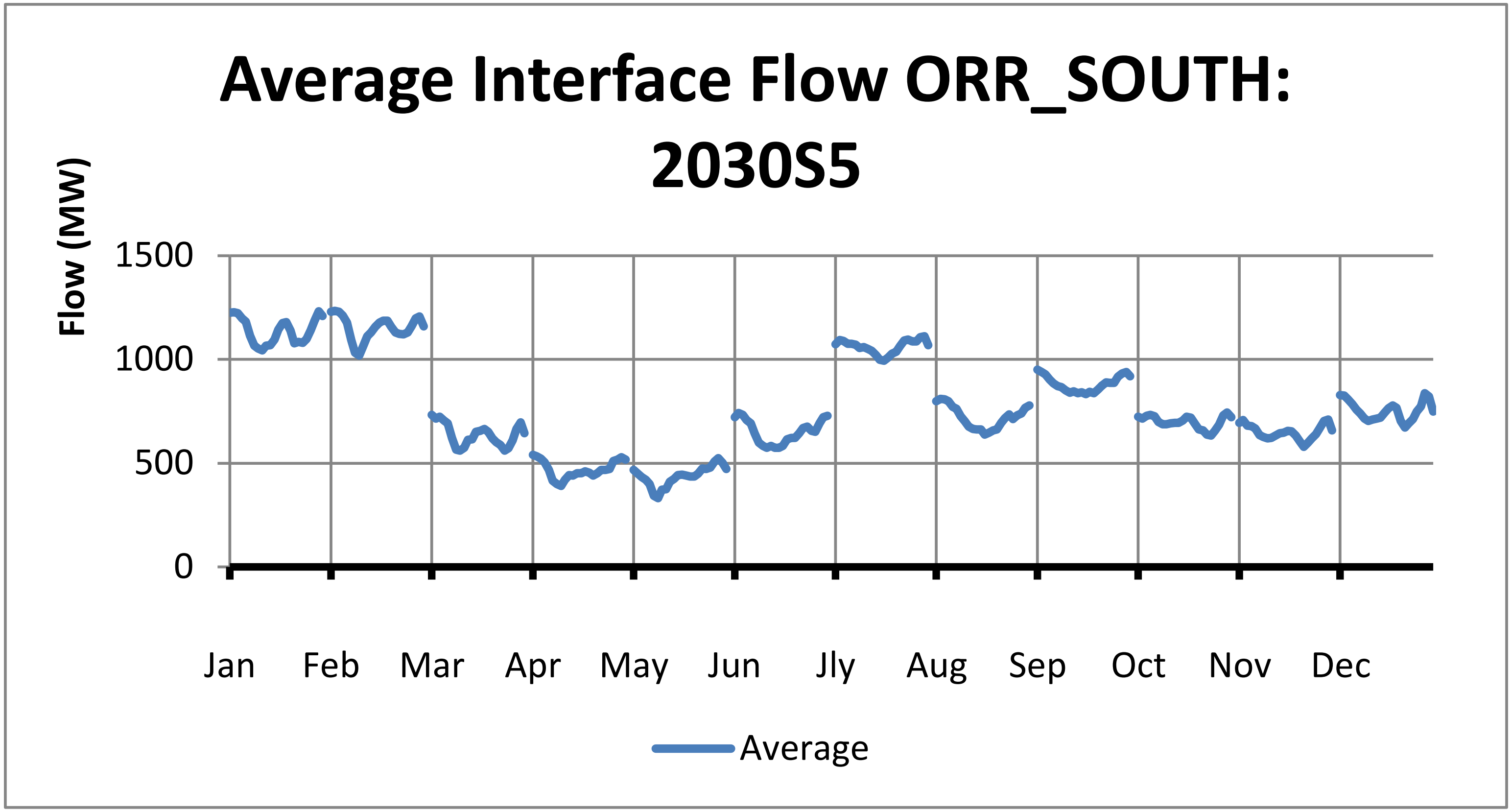
Diurnal Interface Flow – Orrington South 2030 Scenario 3



Diurnal Interface Flow – Orrington South 2030 Scenario 4



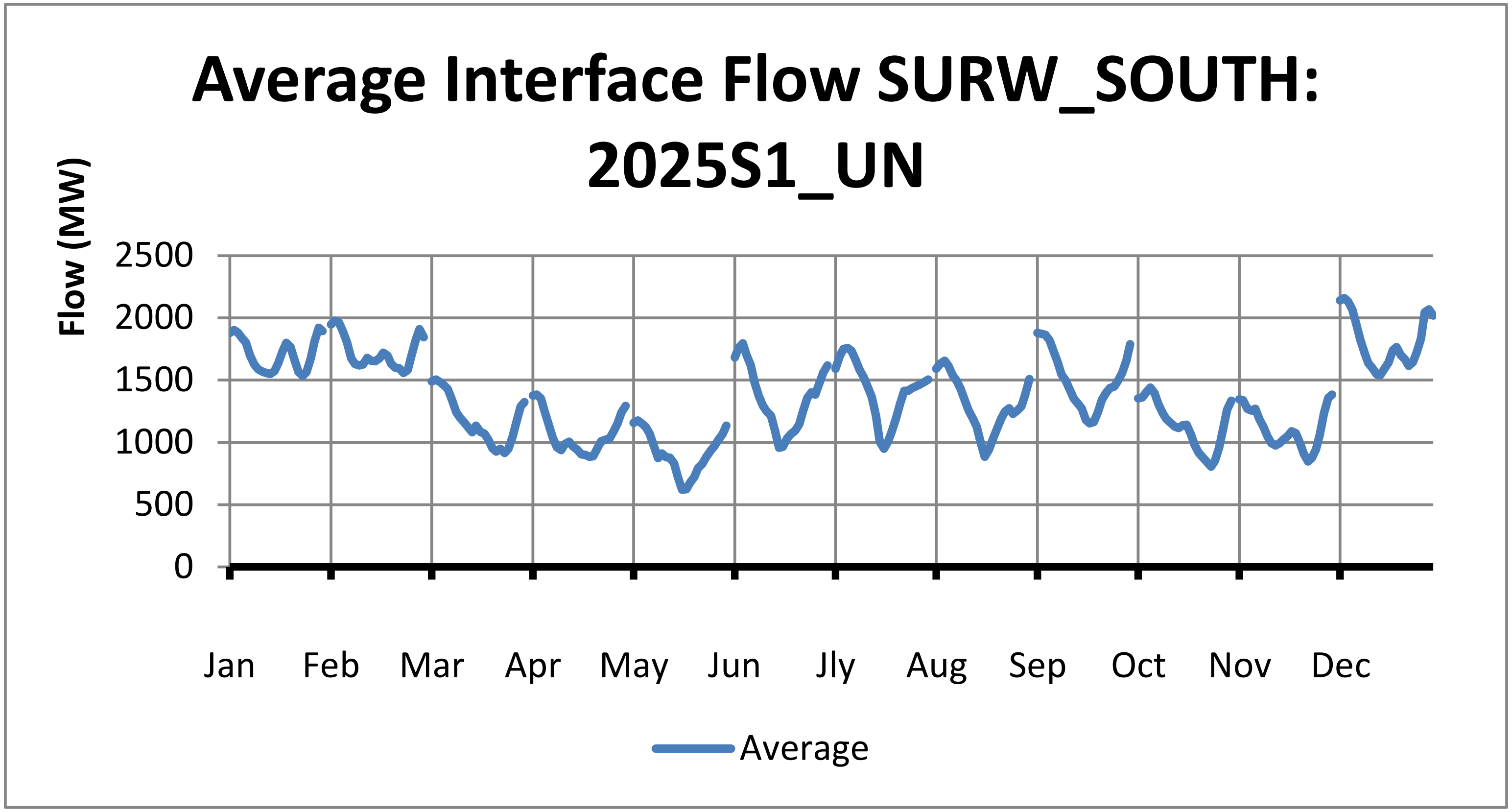
Diurnal Interface Flow – Orrington South 2030 Scenario 5



DIURNAL FLOWS ACROSS INTERFACES 2025 AND 2030

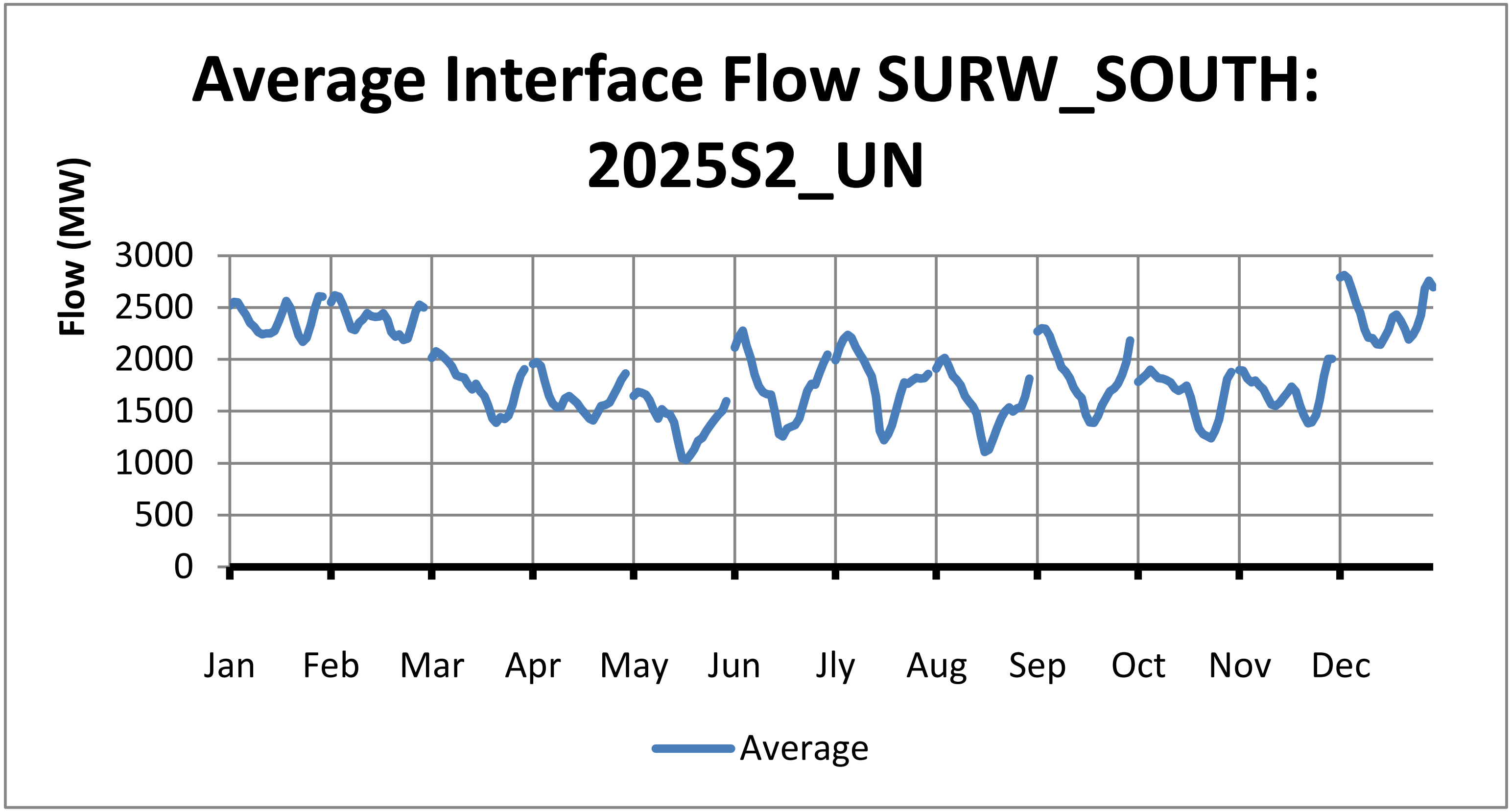
Surowiec South Interface

Diurnal Interface Flow – Surowiec South 2030 Scenario 5

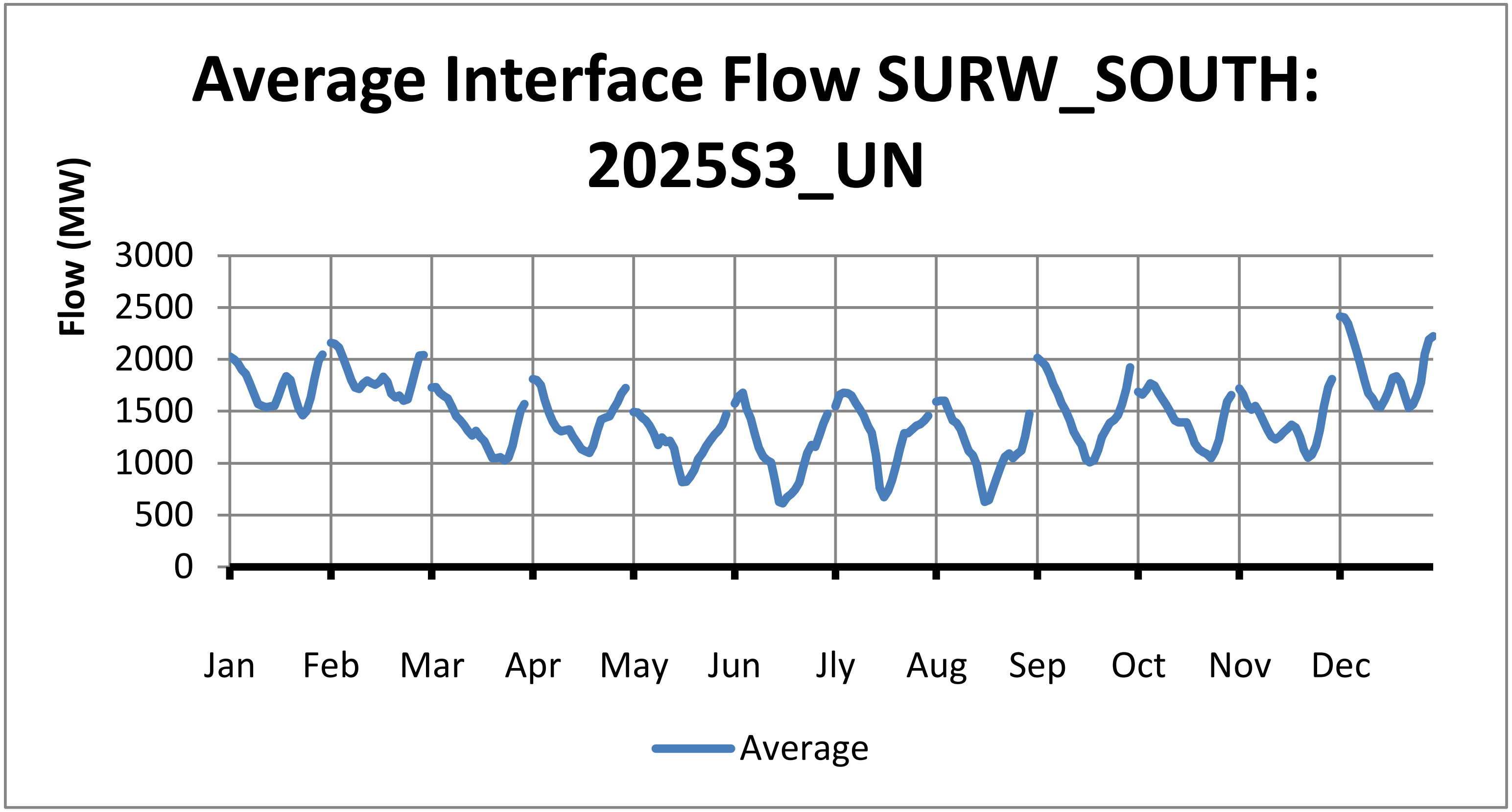


ISO-NE PUBLIC

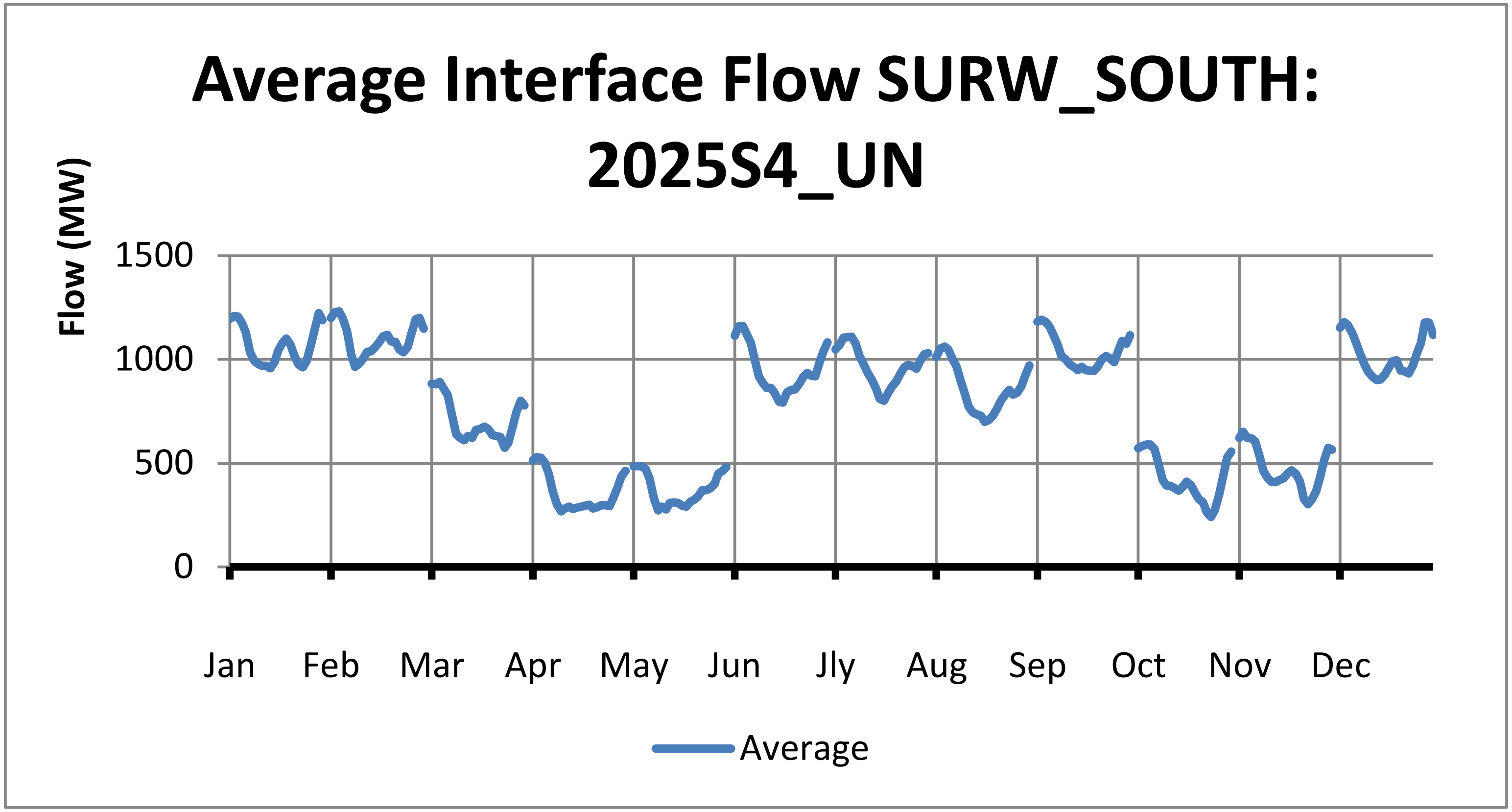
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



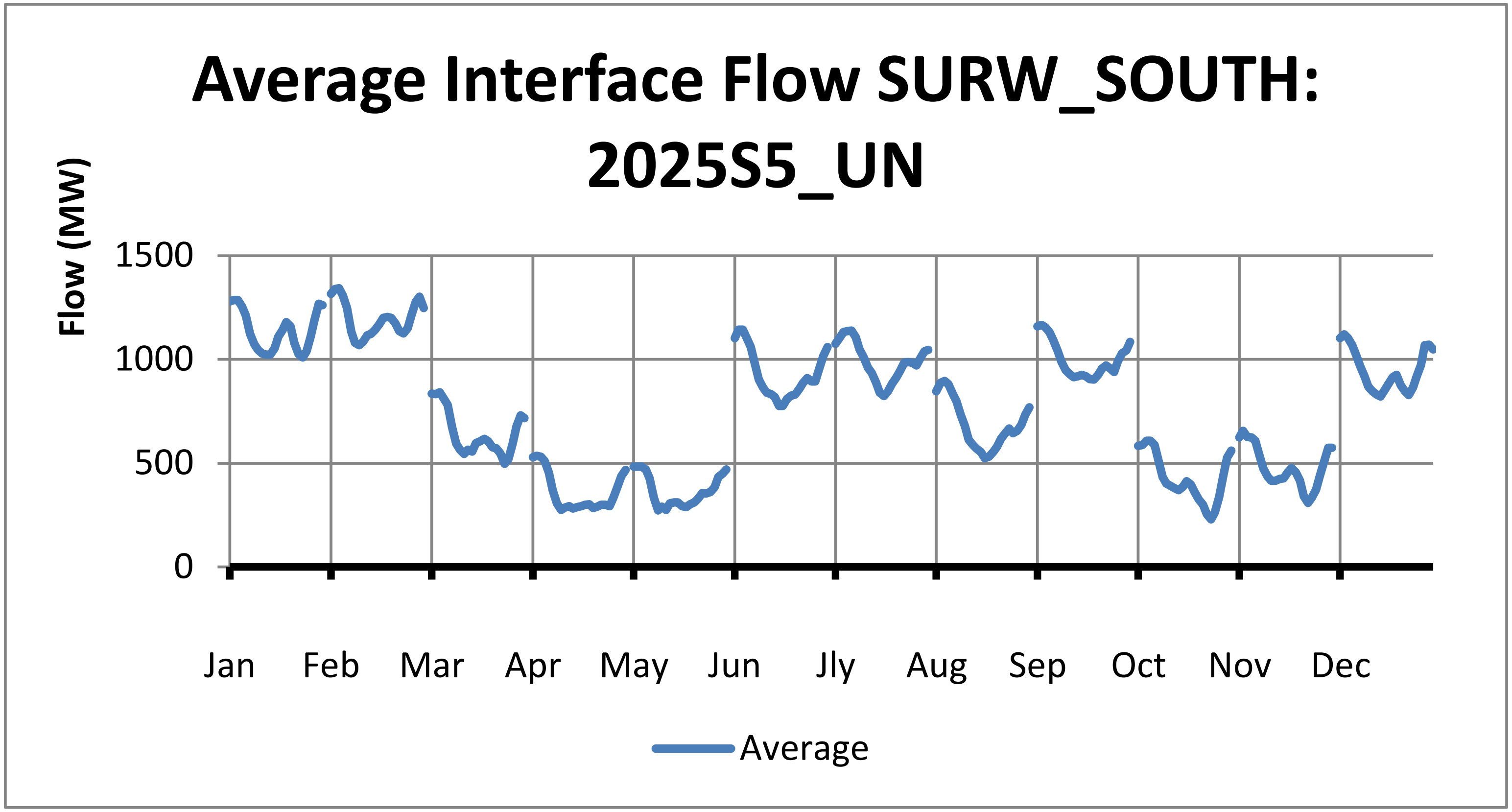
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



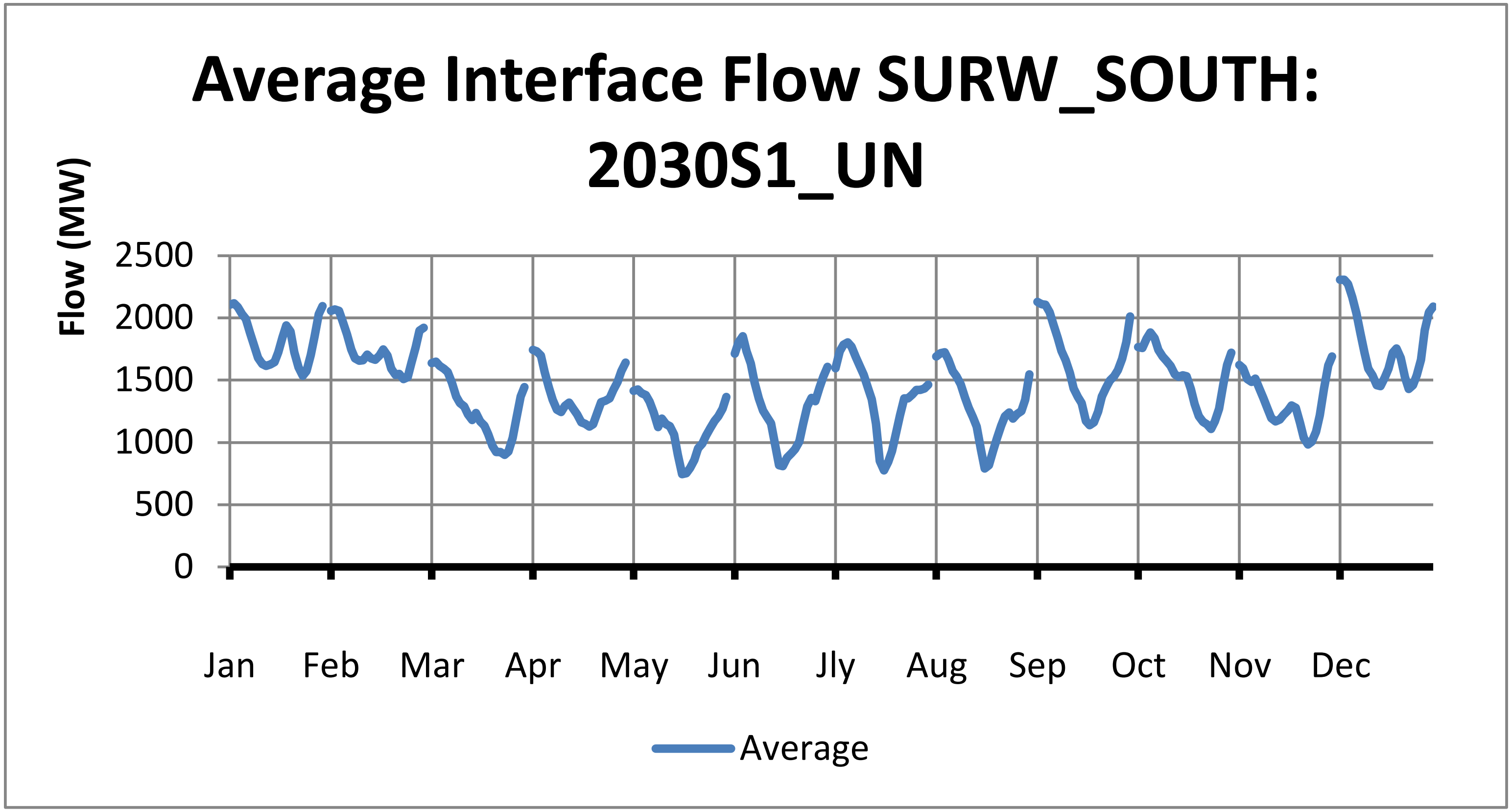
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



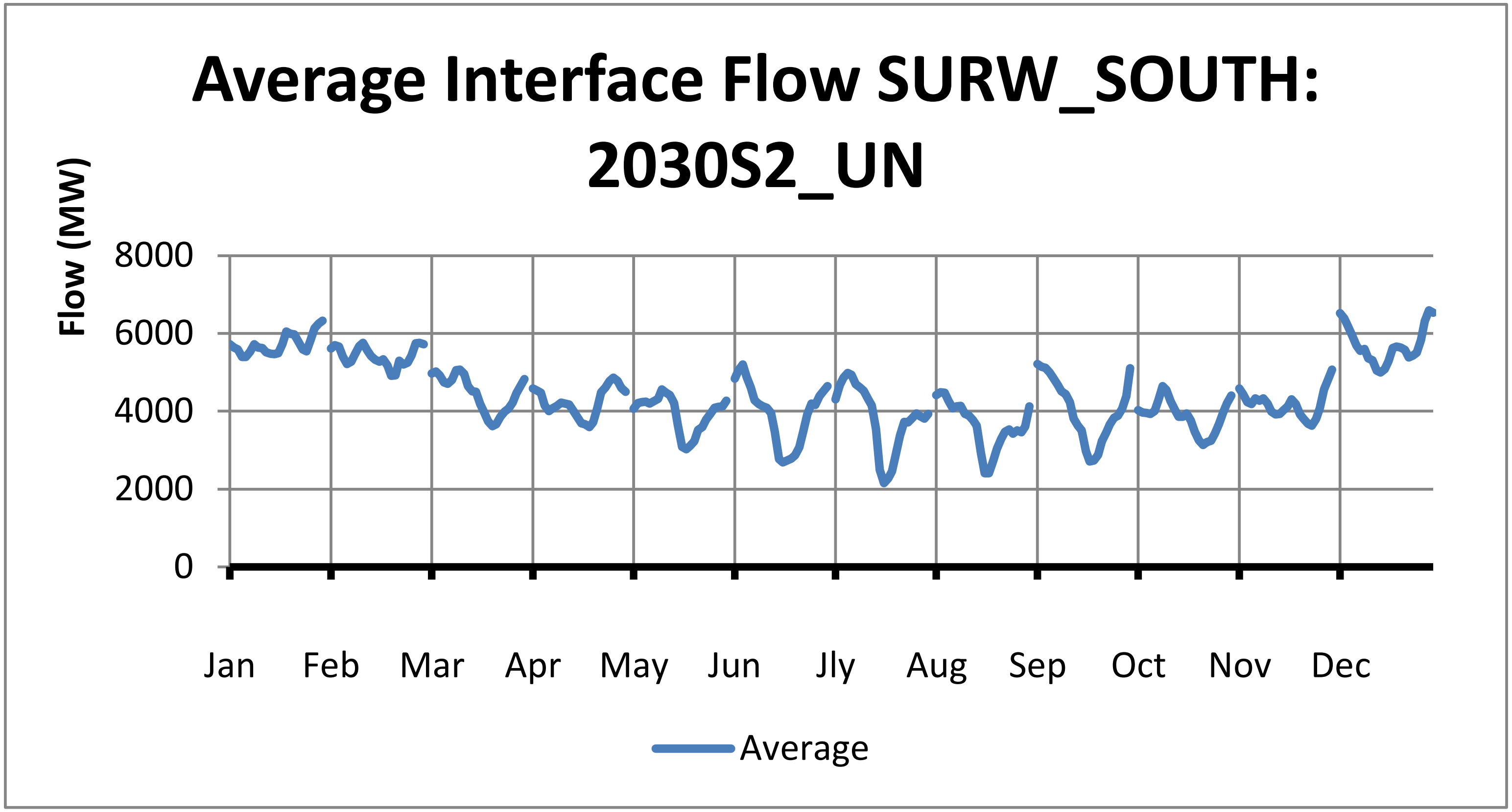
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



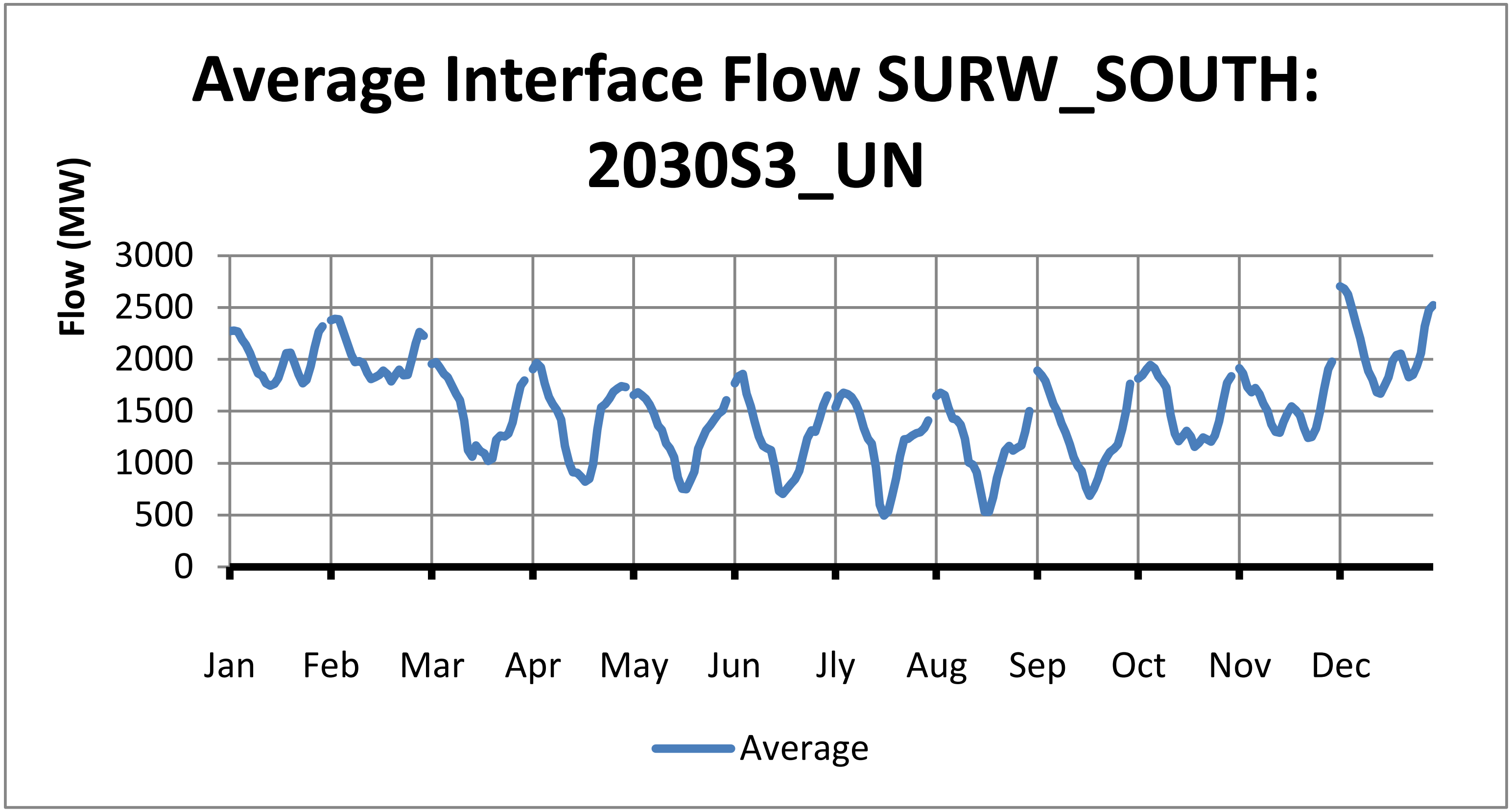
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



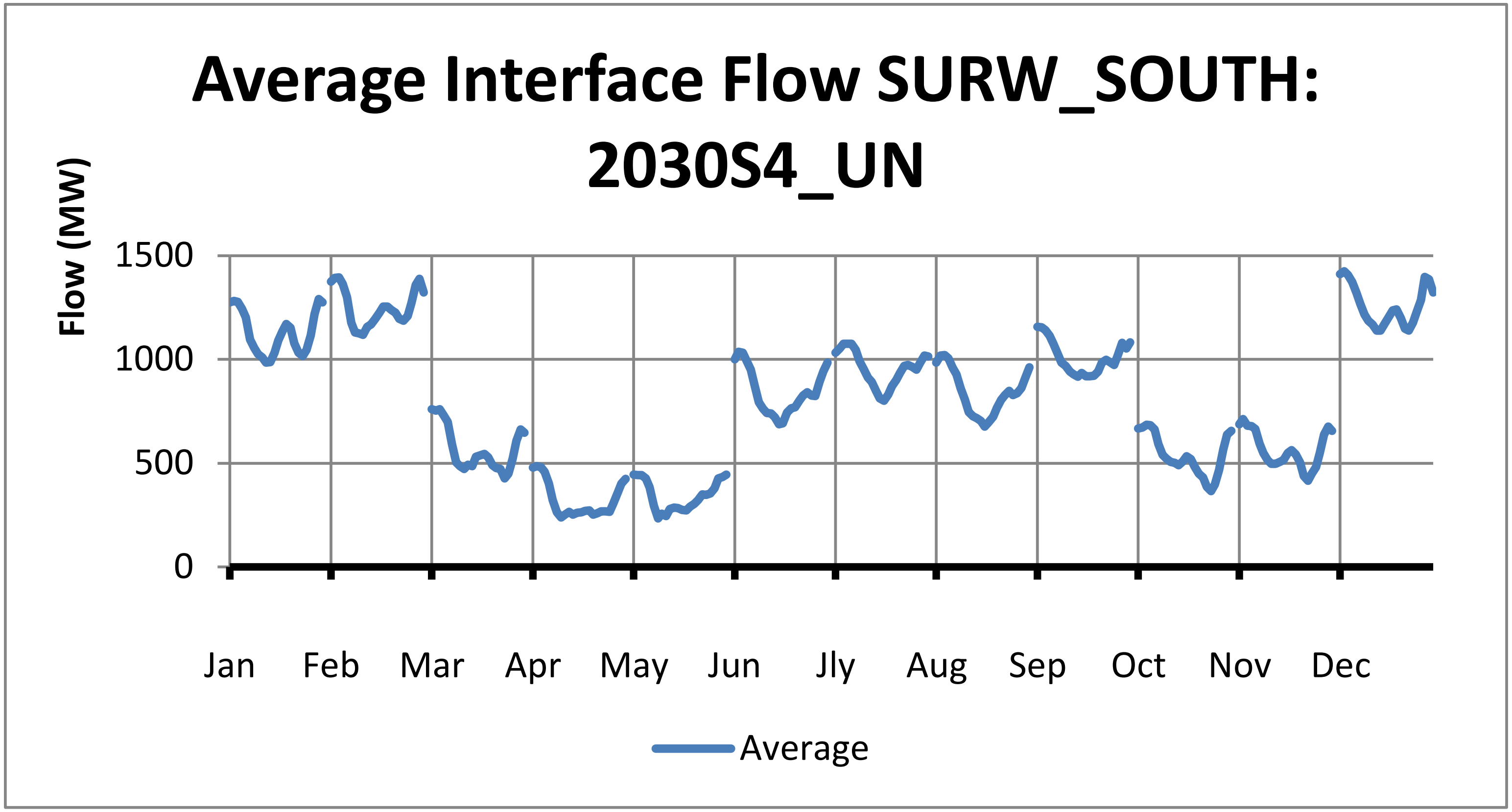
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



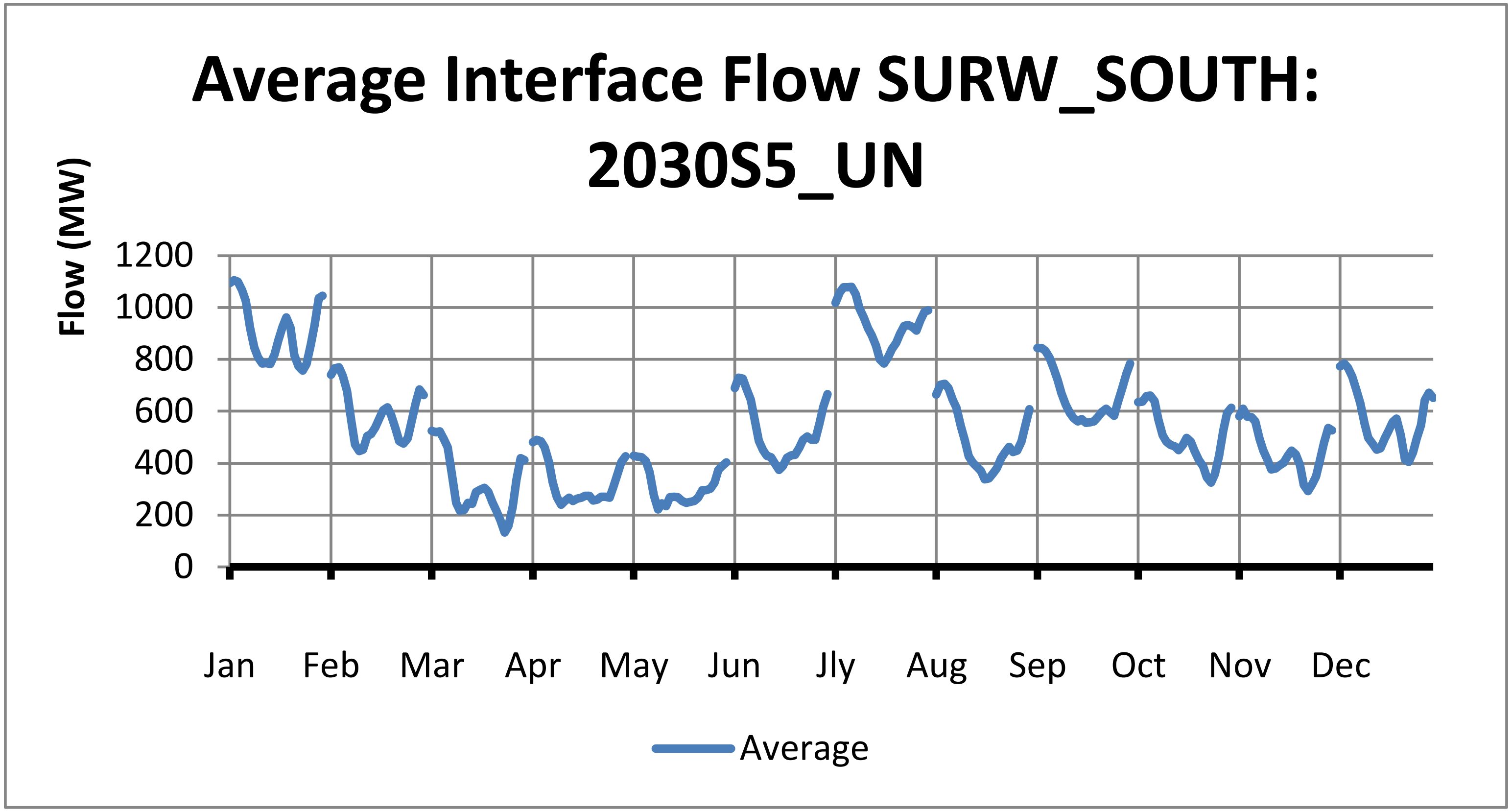
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



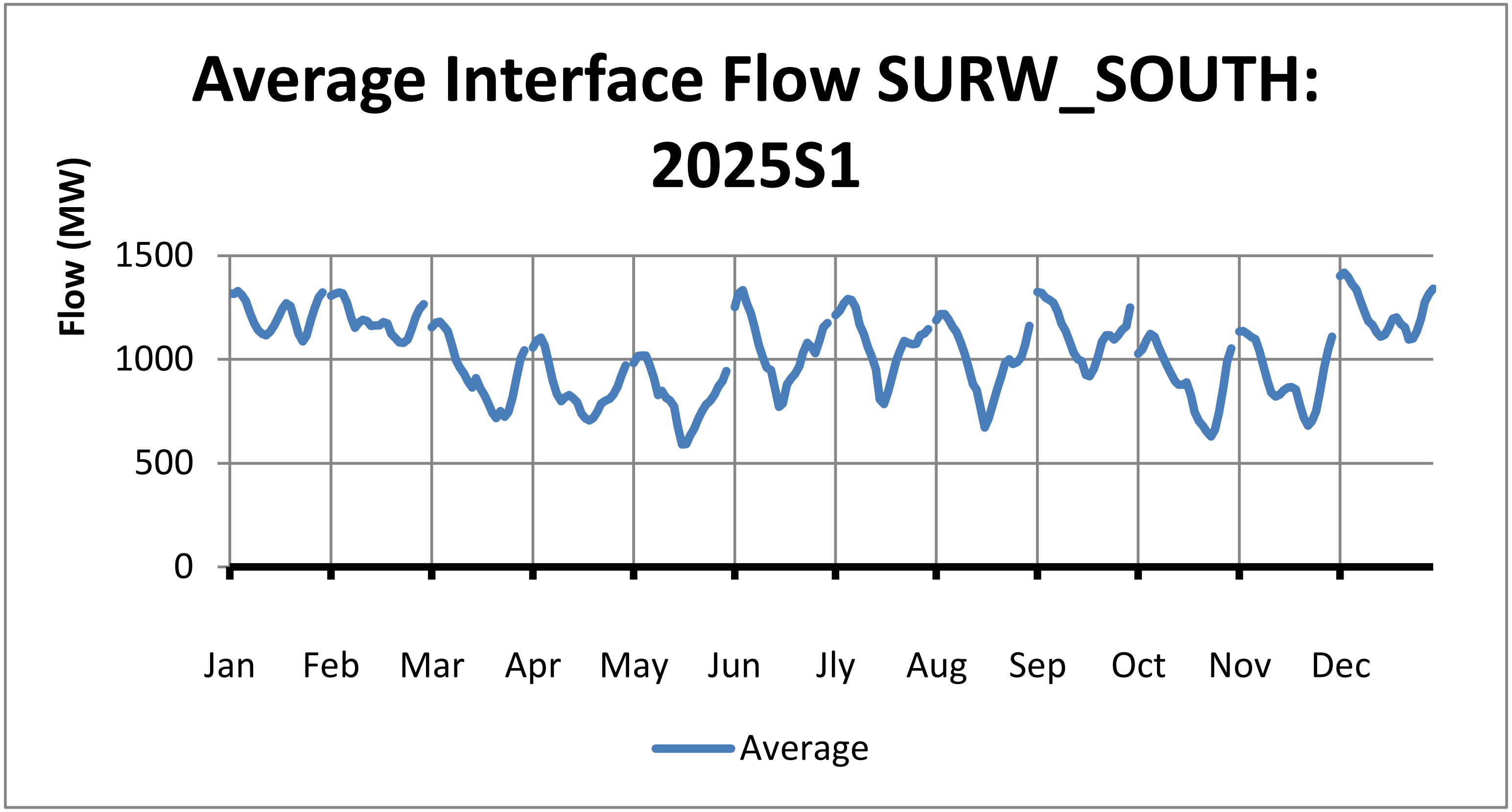
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



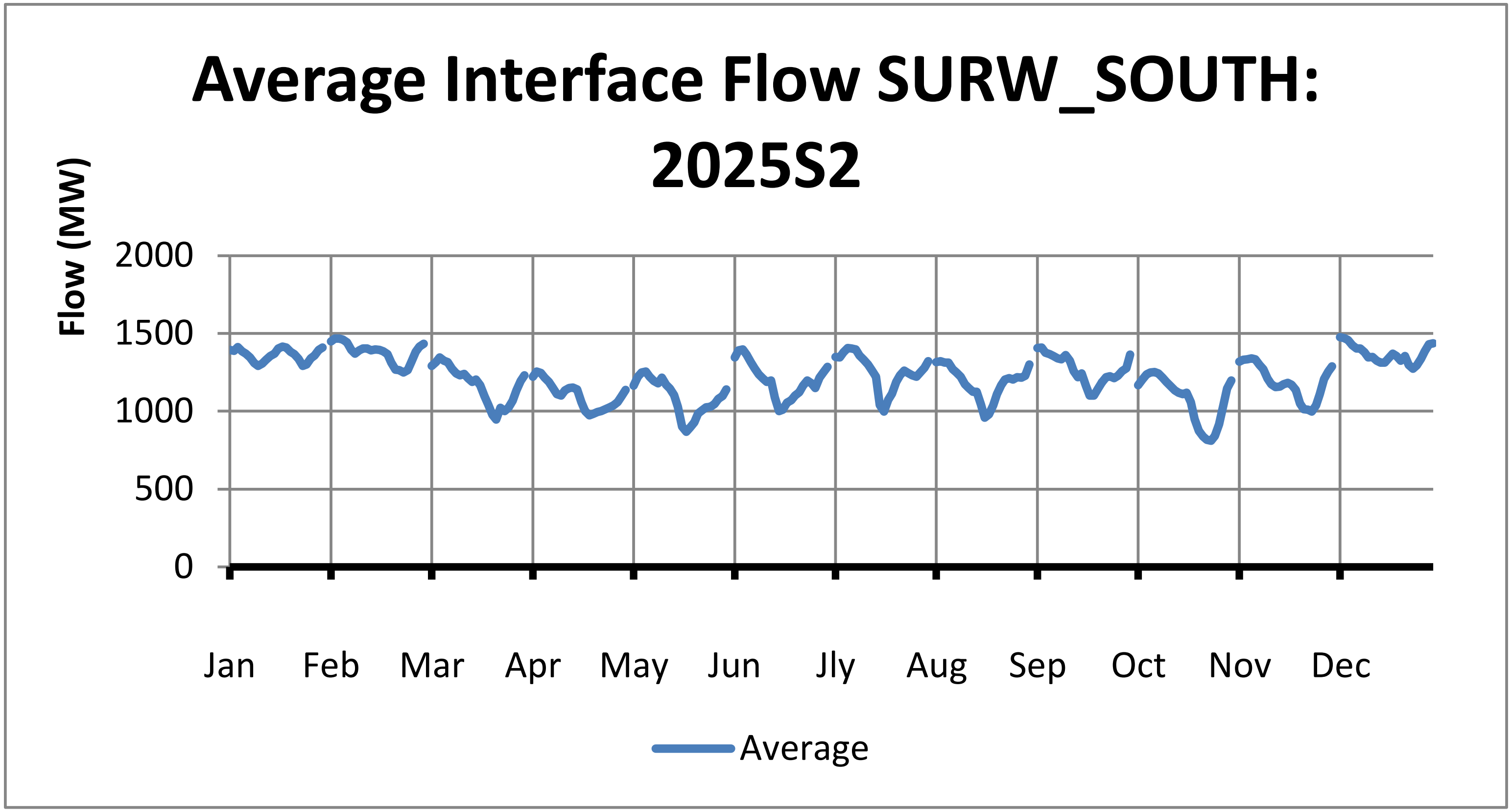
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



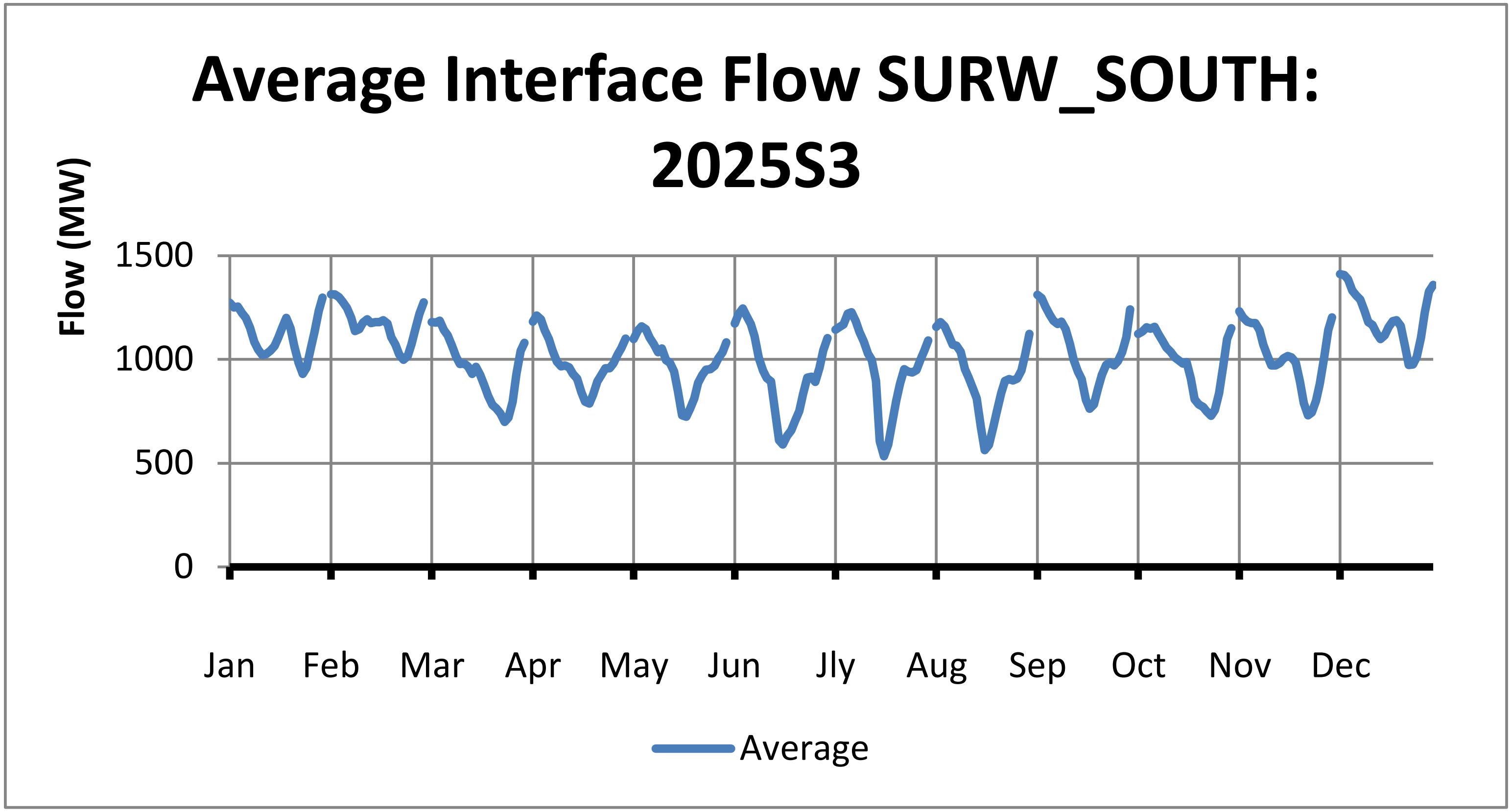
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



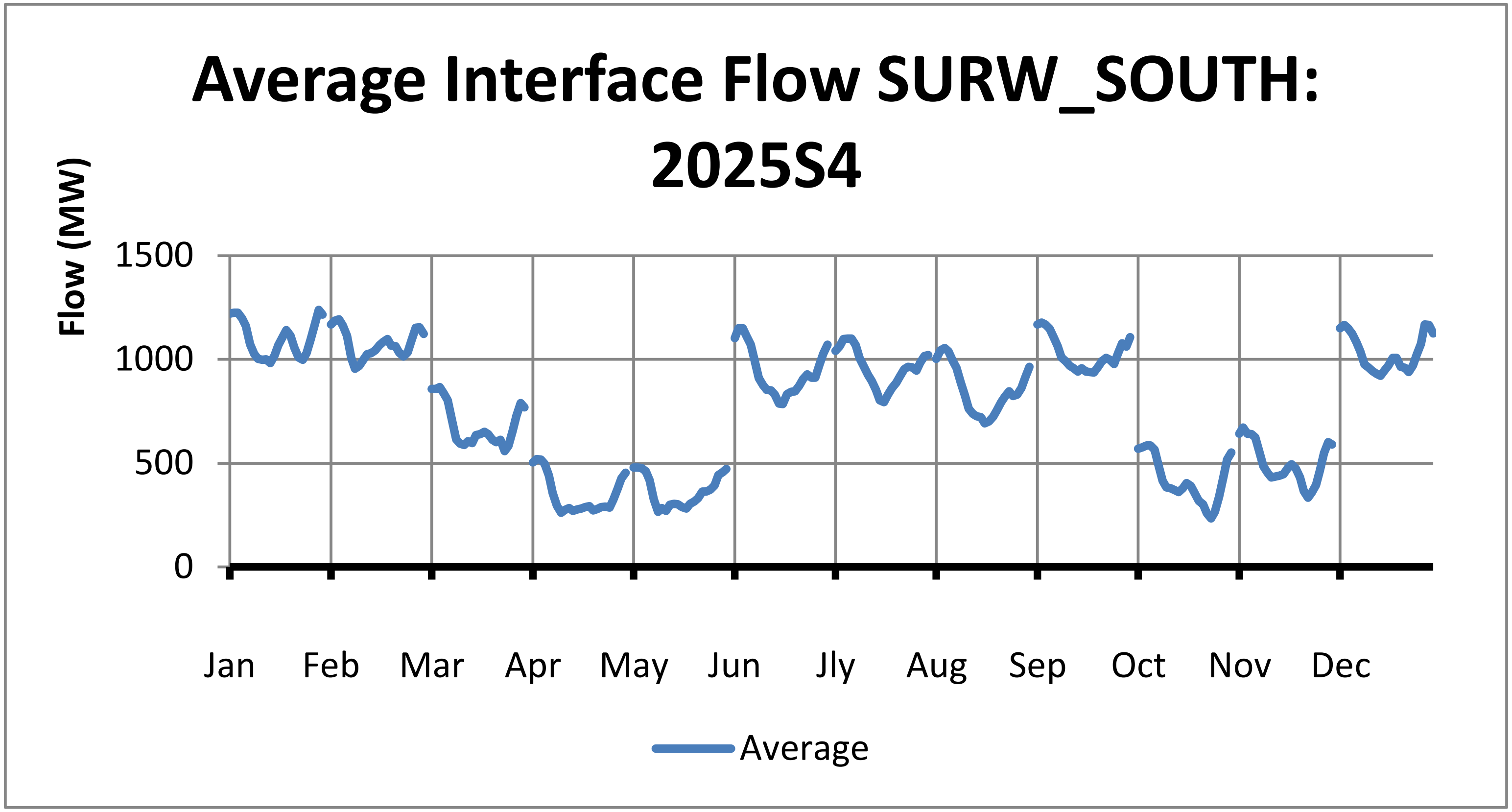
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



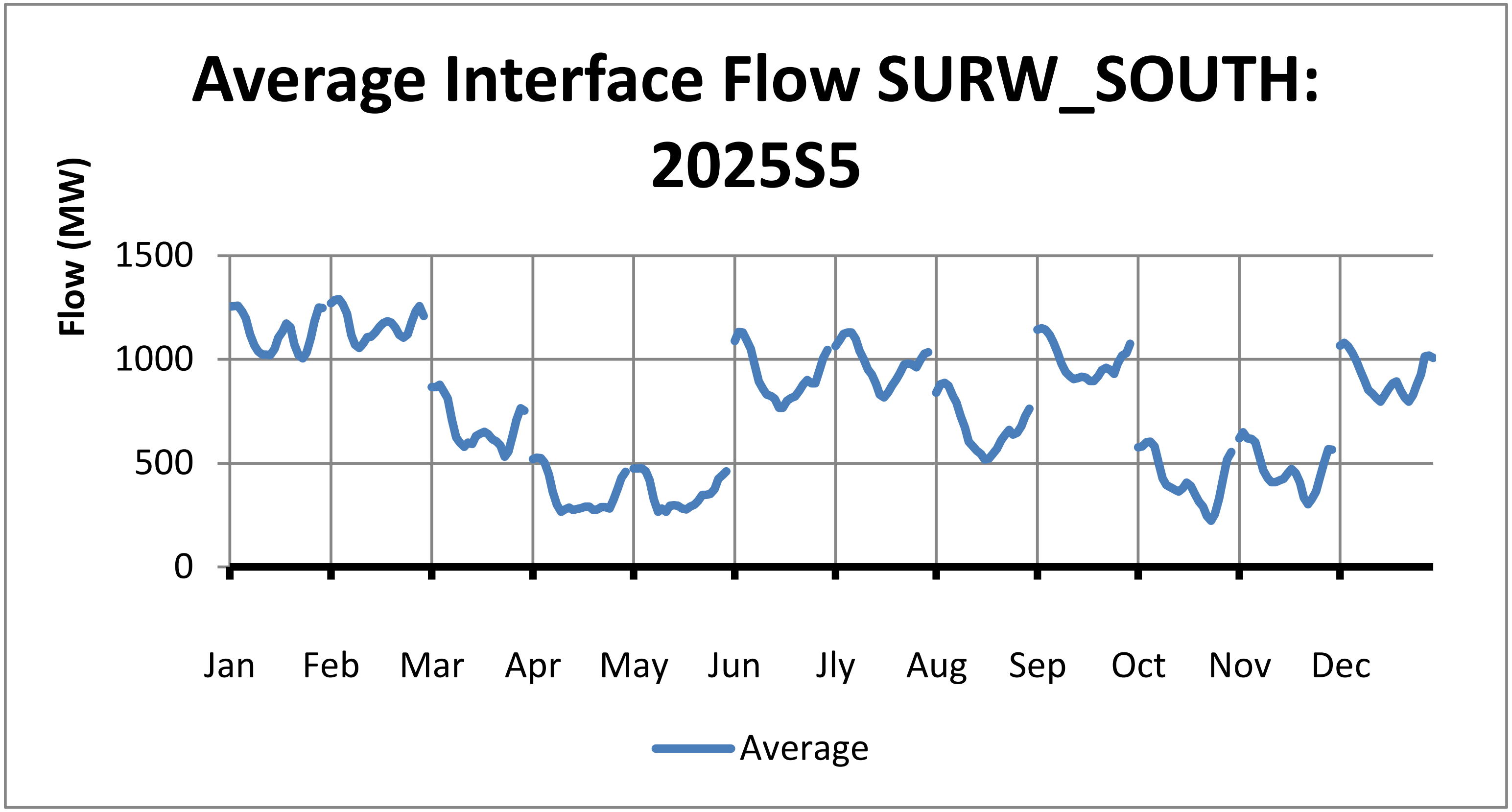
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



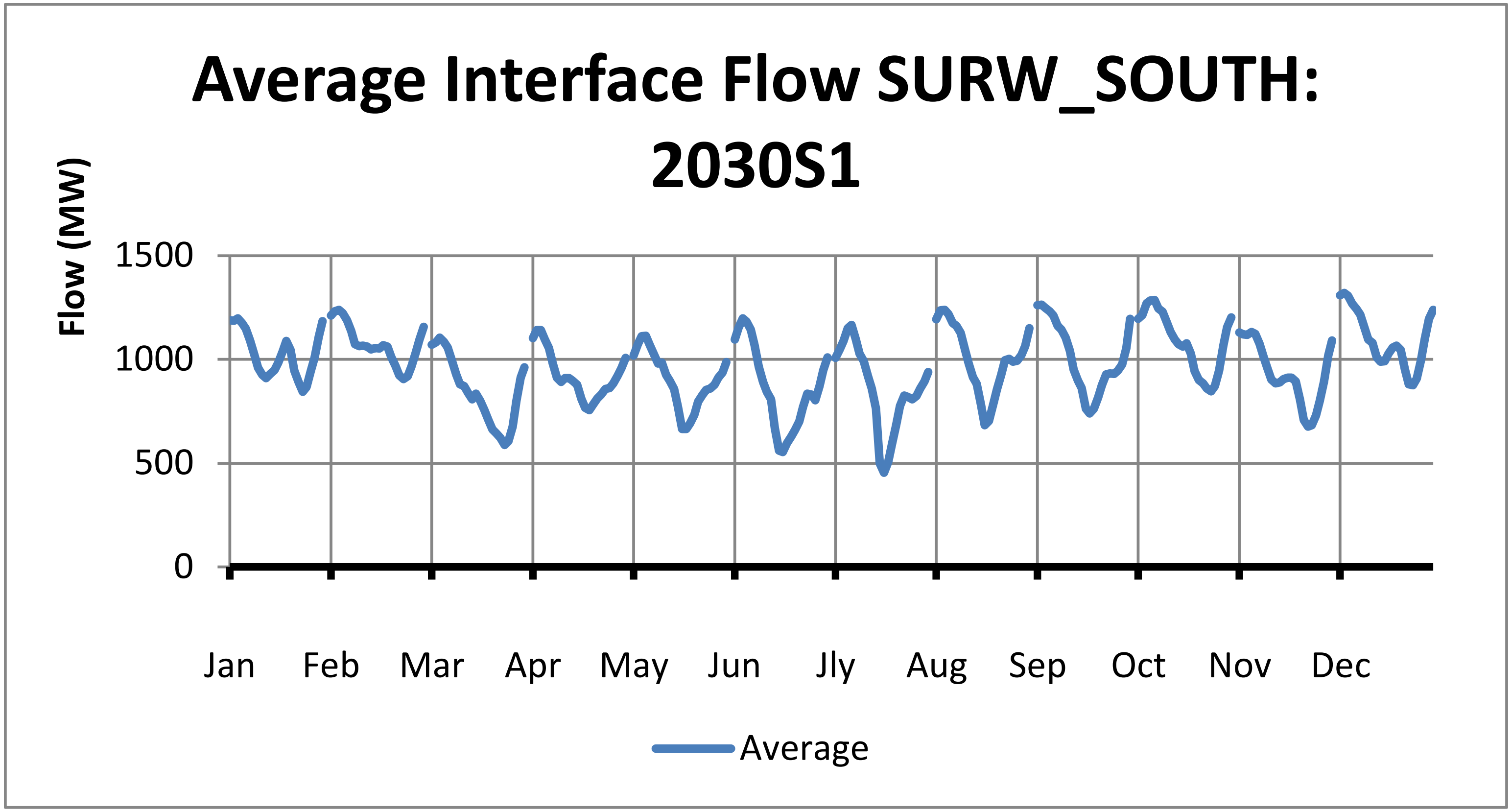
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



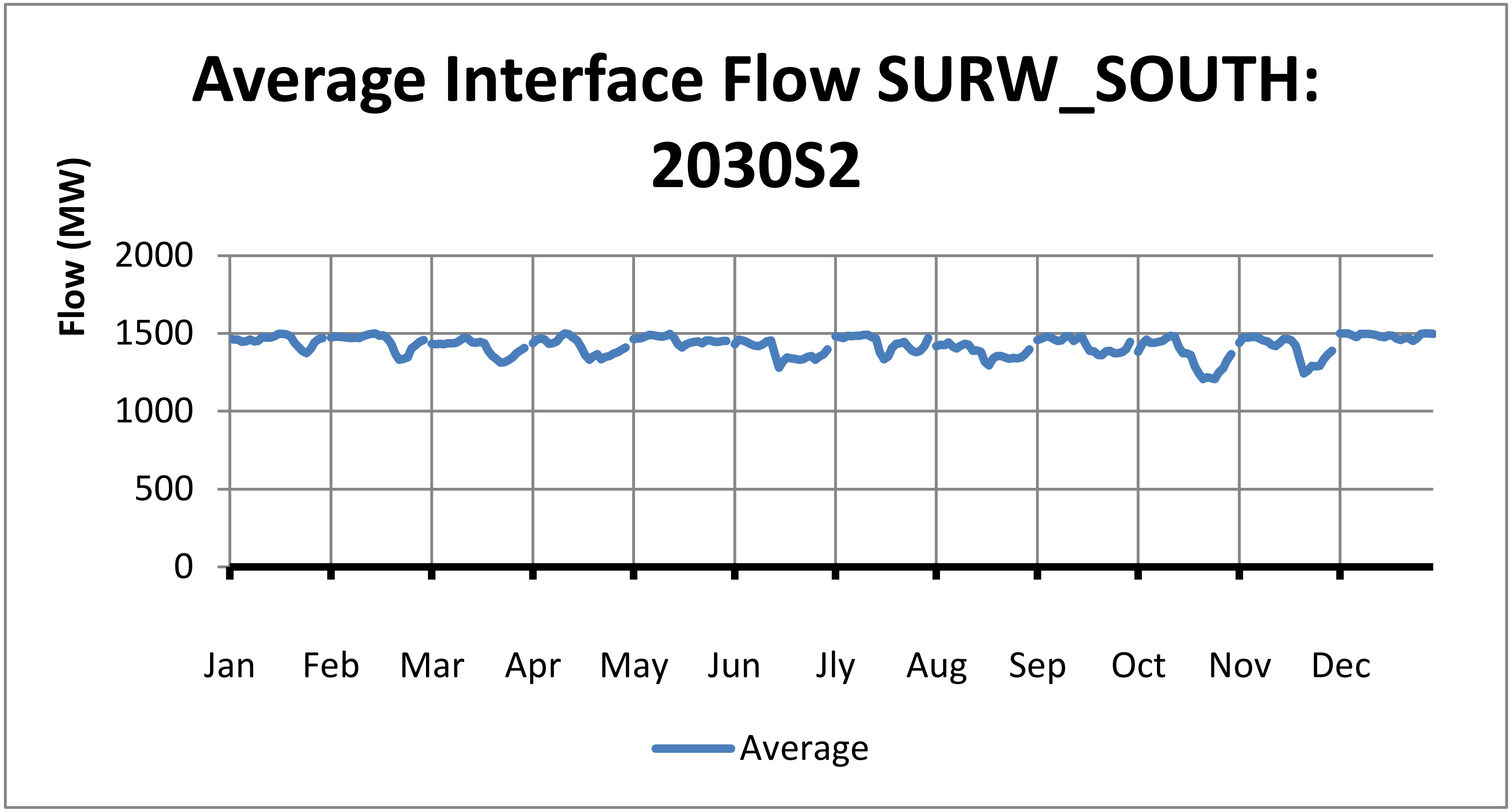
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



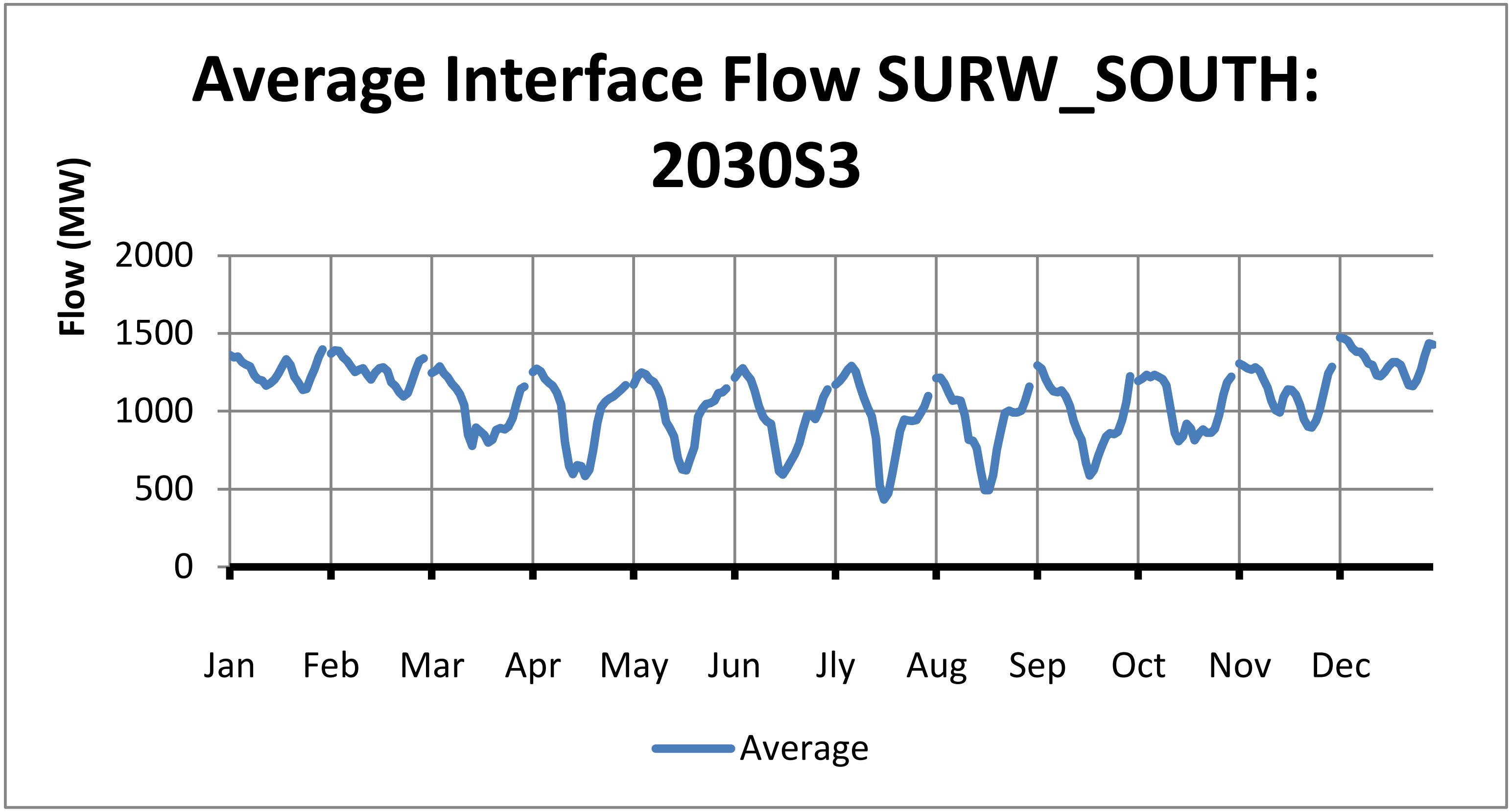
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



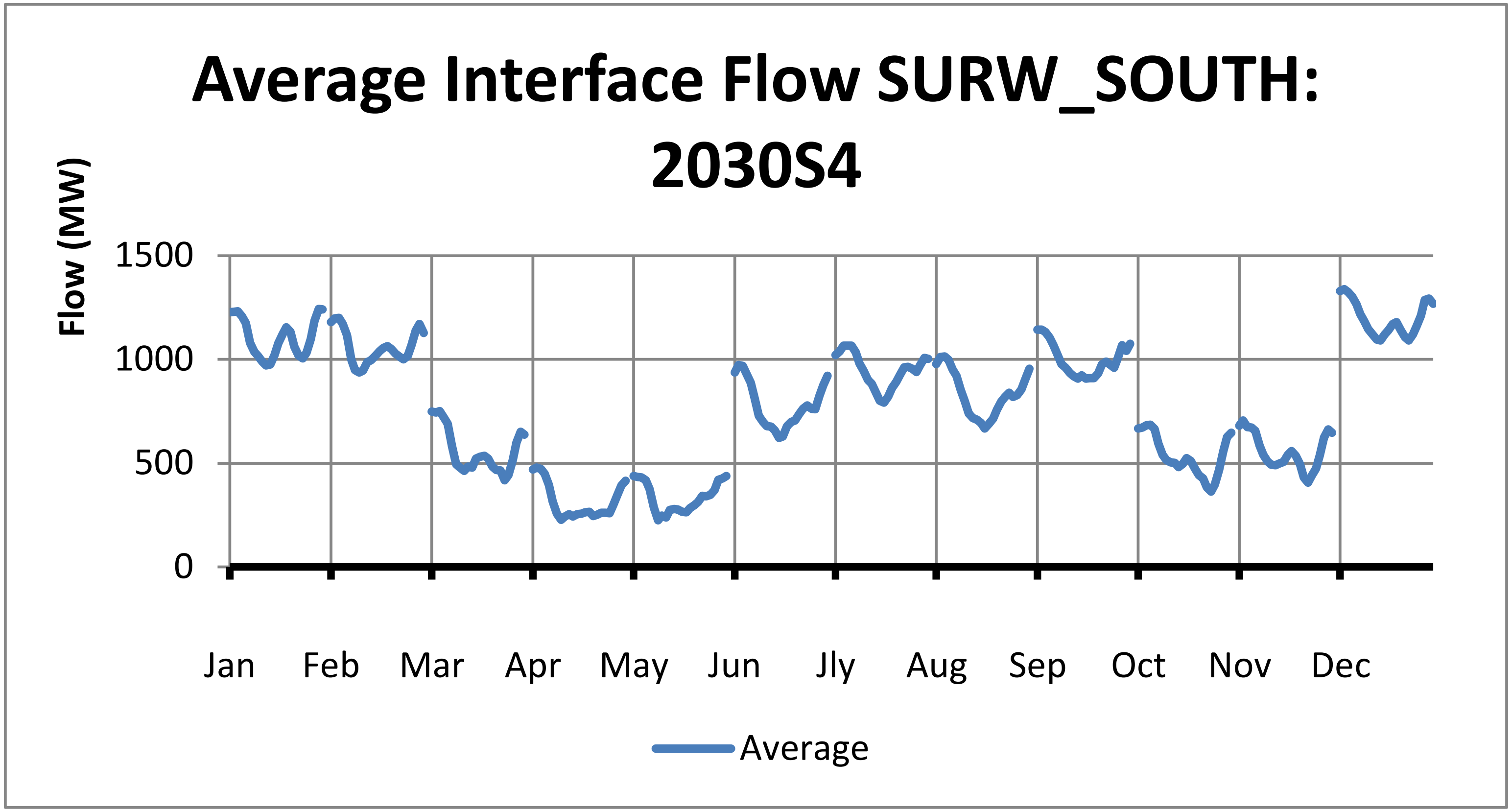
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



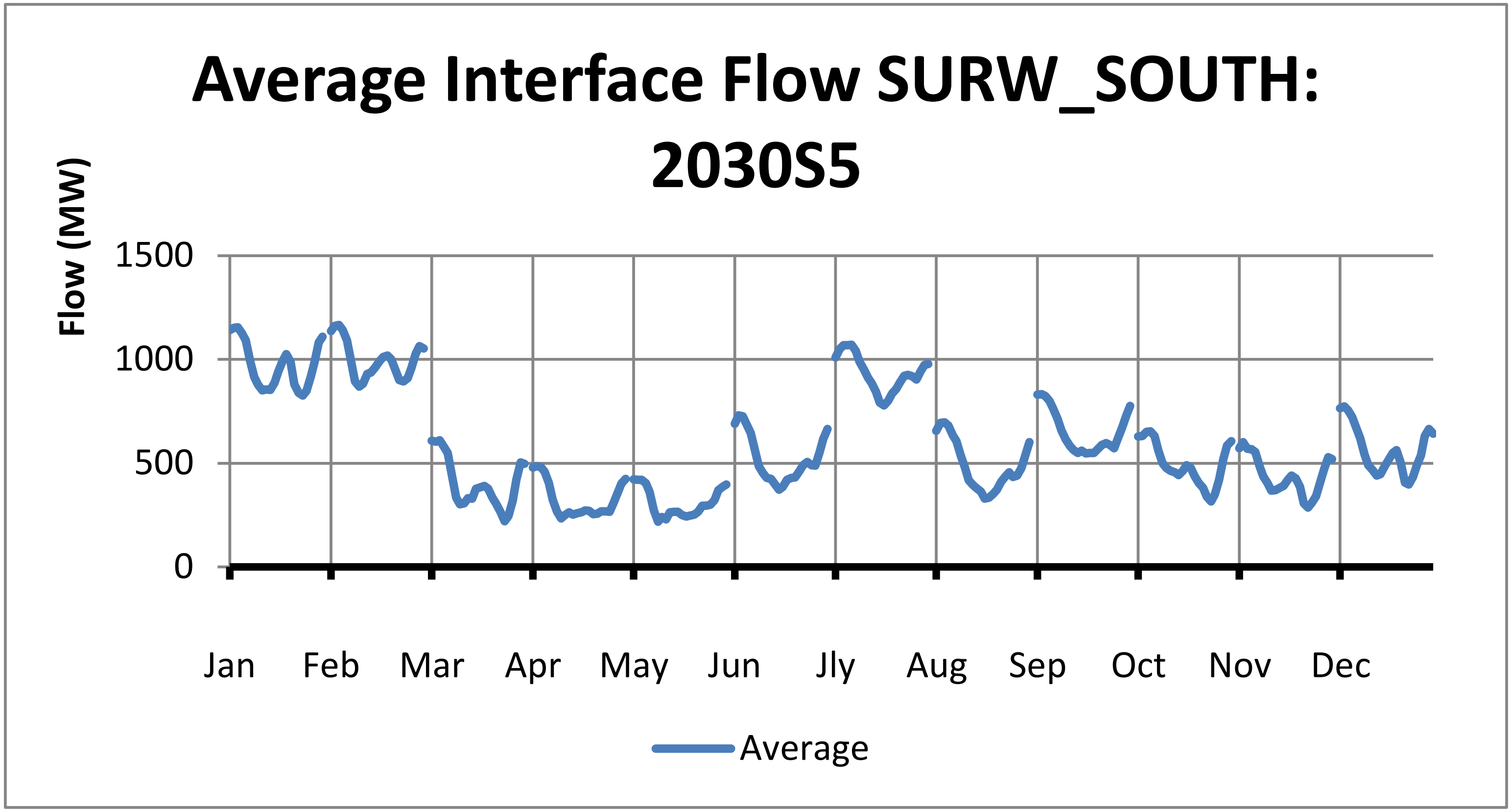
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



Diurnal Interface Flow – Surowiec South 2030 Scenario 5



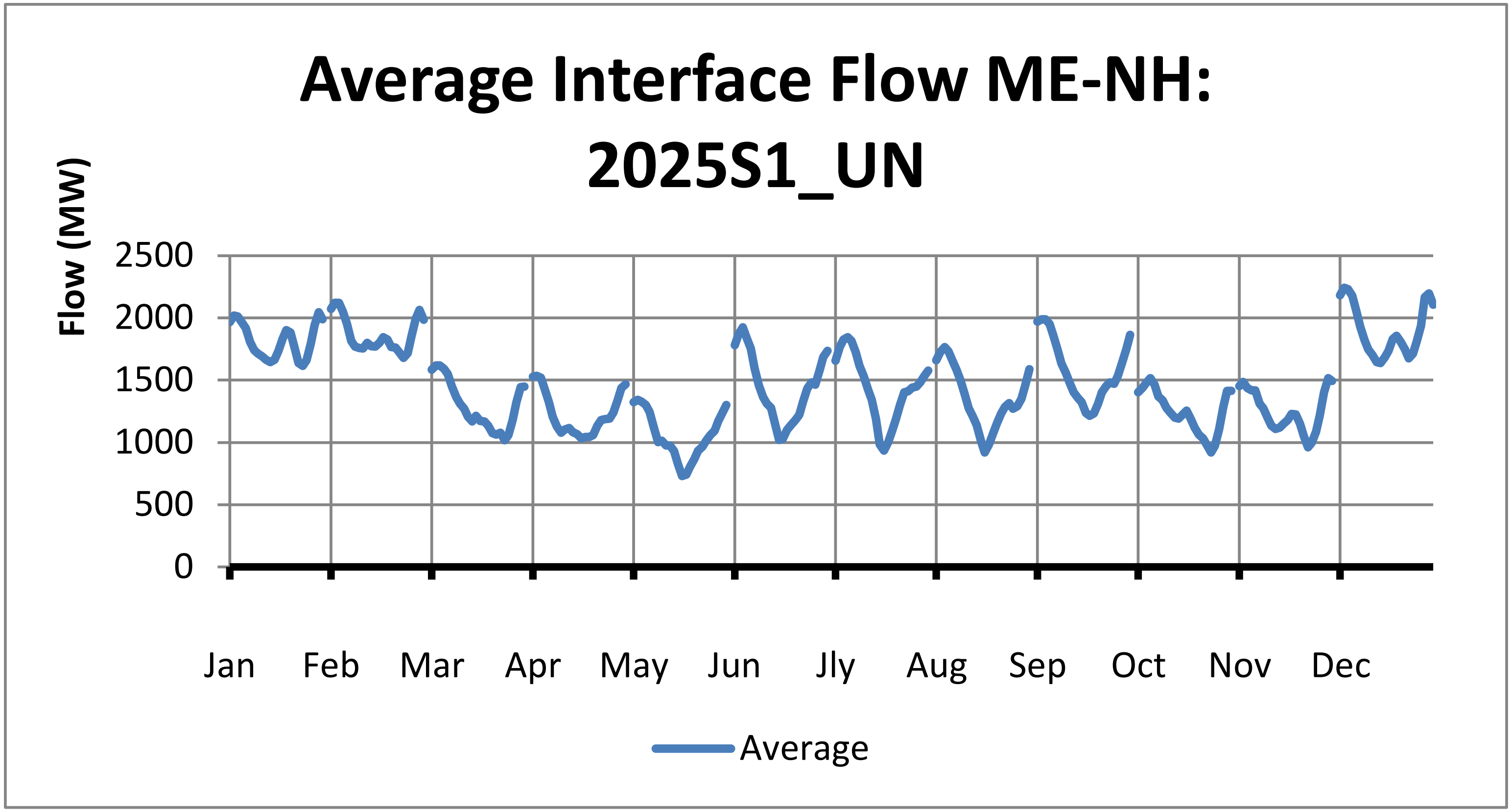
Diurnal Interface Flow – Surowiec South 2030 Scenario 5



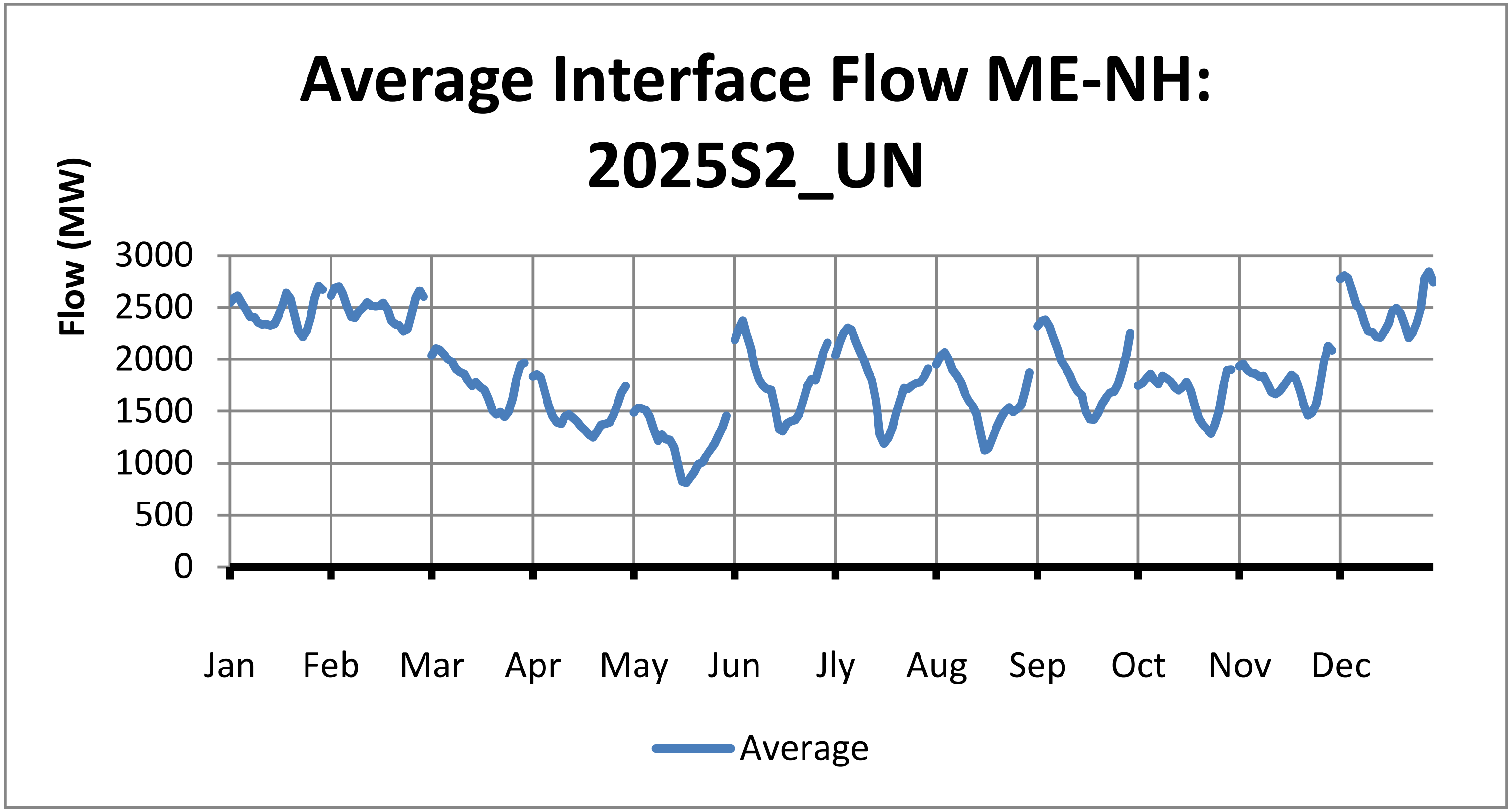
DIURNAL FLOWS ACROSS INTERFACES 2025 AND 2030

Maine – New Hampshire Interface

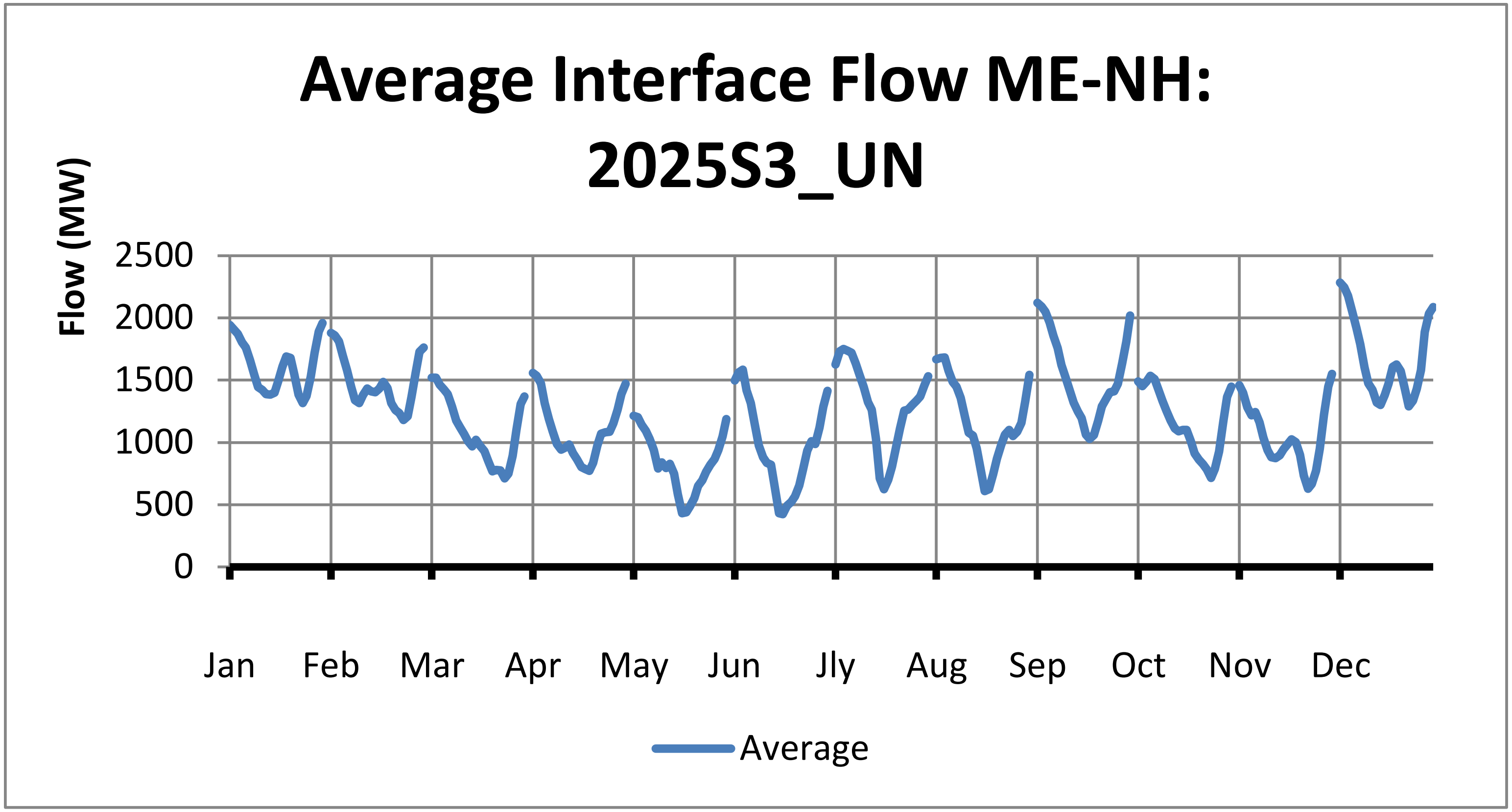
Diurnal Interface Flow: ME-NH 2025 Unconstrained Scenario 1



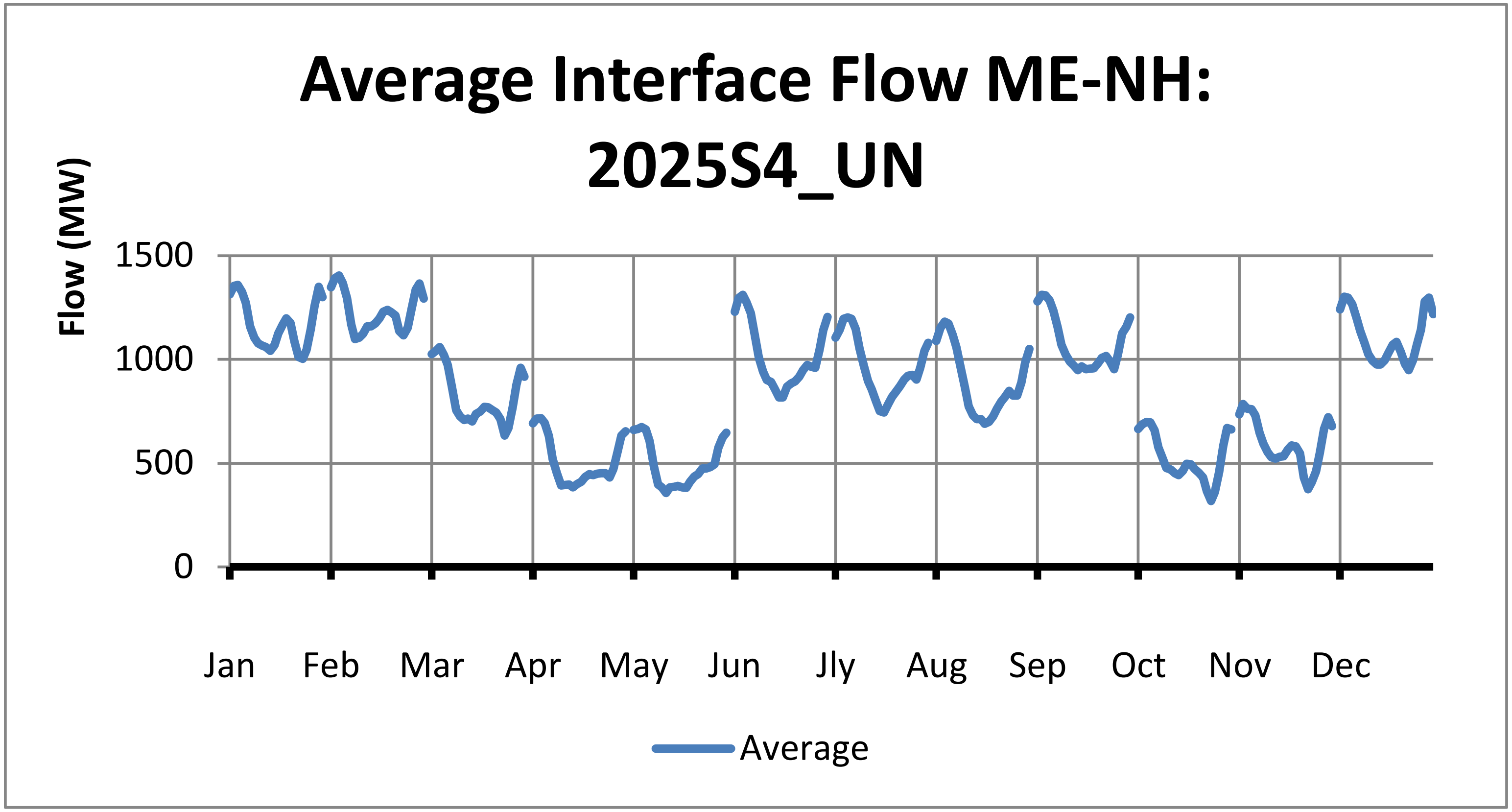
Diurnal Interface Flow: ME-NH
2025 Unconstrained Scenario 2



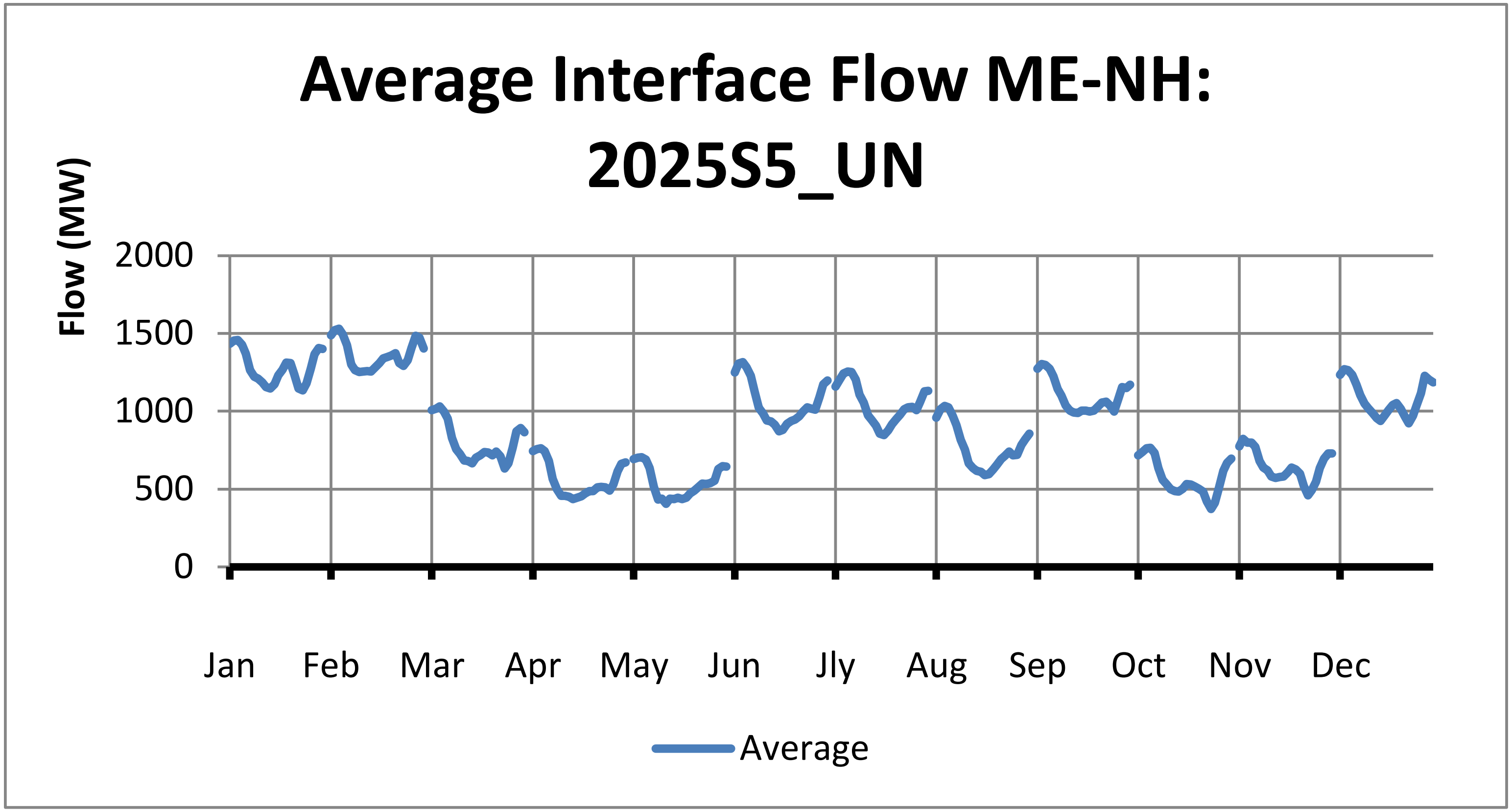
Diurnal Interface Flow: ME-NH 2025 Unconstrained Scenario 3



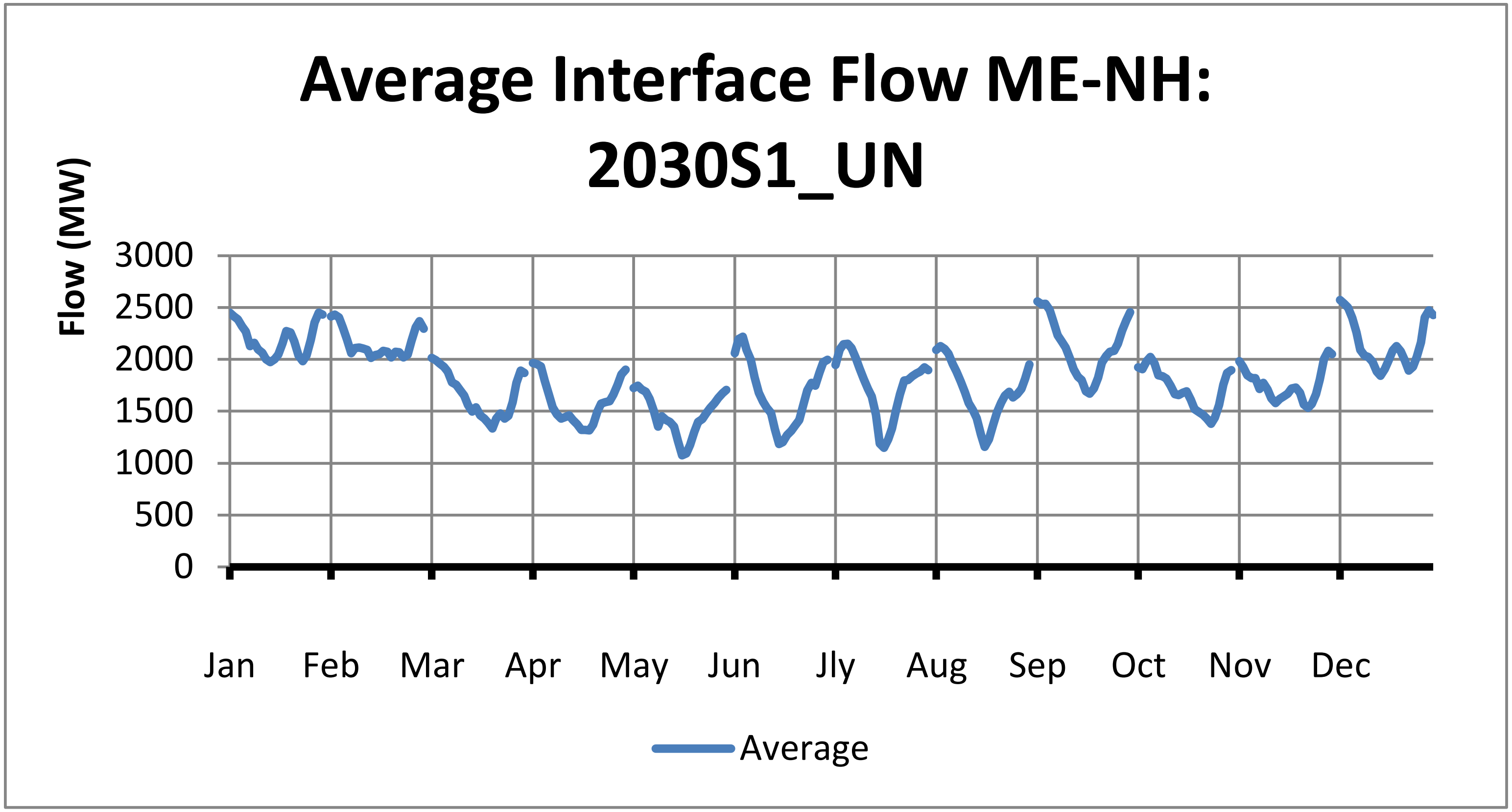
Diurnal Interface Flow: ME-NH 2025 Unconstrained Scenario 4



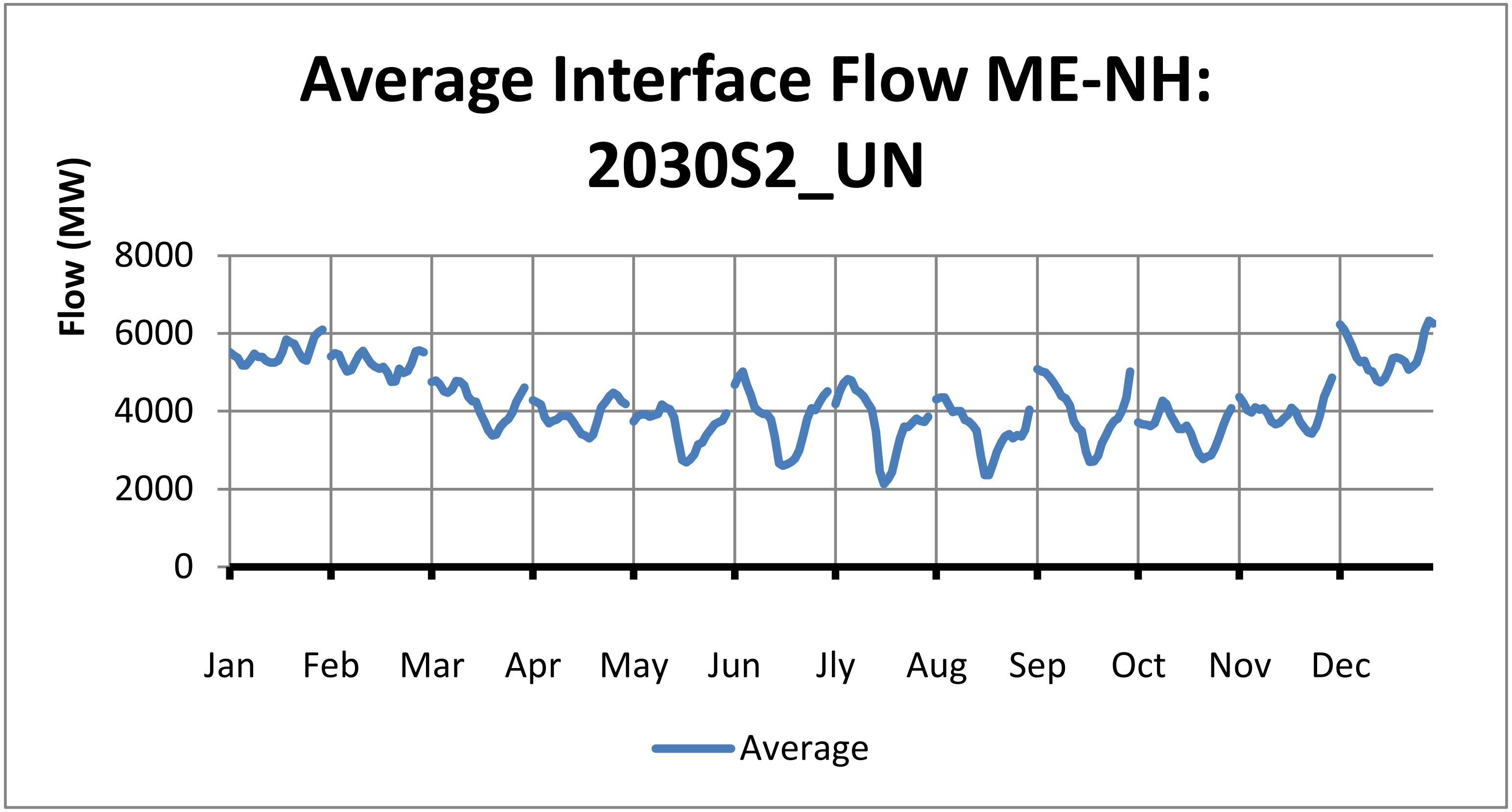
Diurnal Interface Flow: ME-NH
2025 Unconstrained Scenario 5



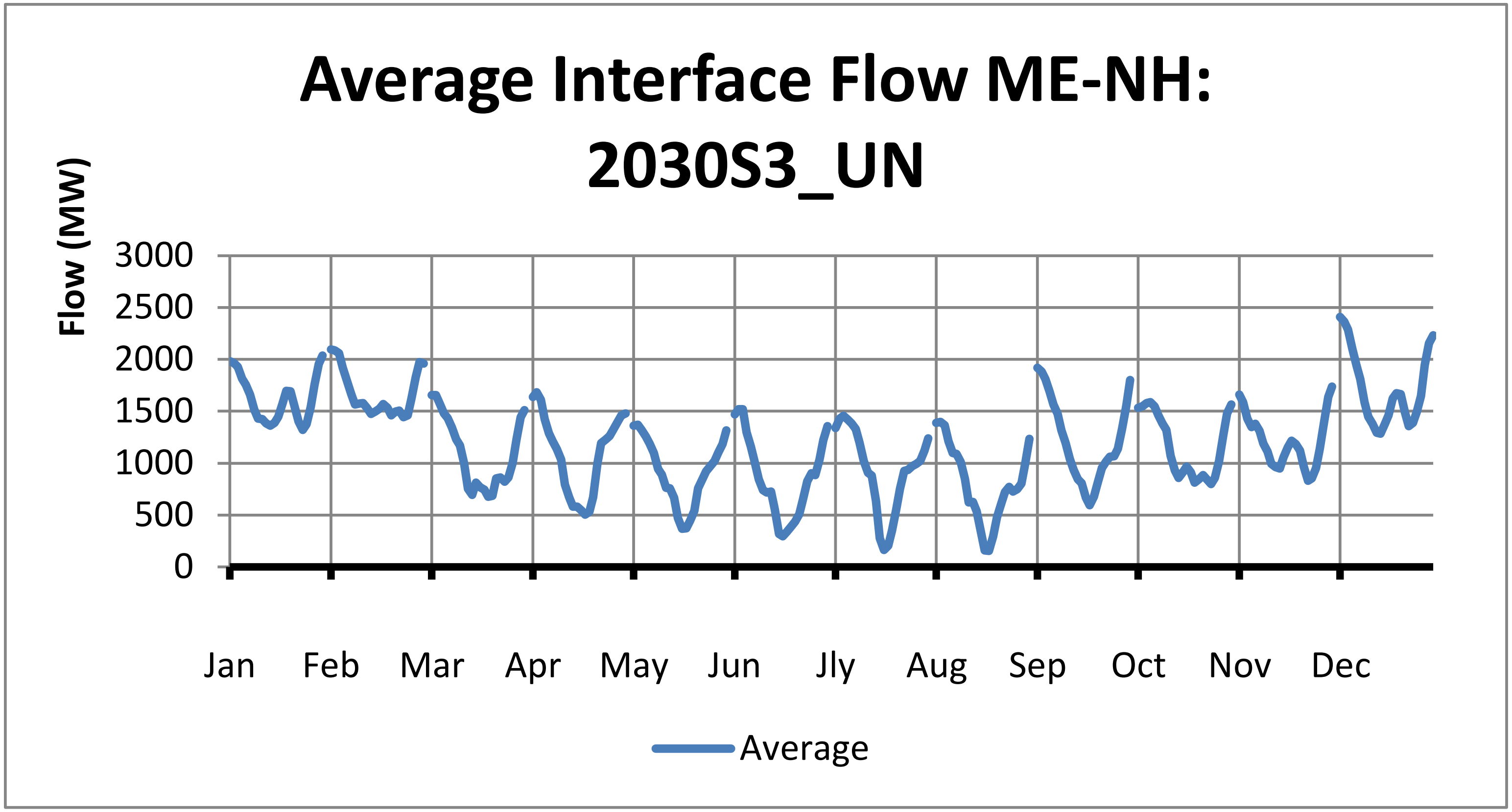
Diurnal Interface Flow: ME-NH
2030 Unconstrained Scenario 1



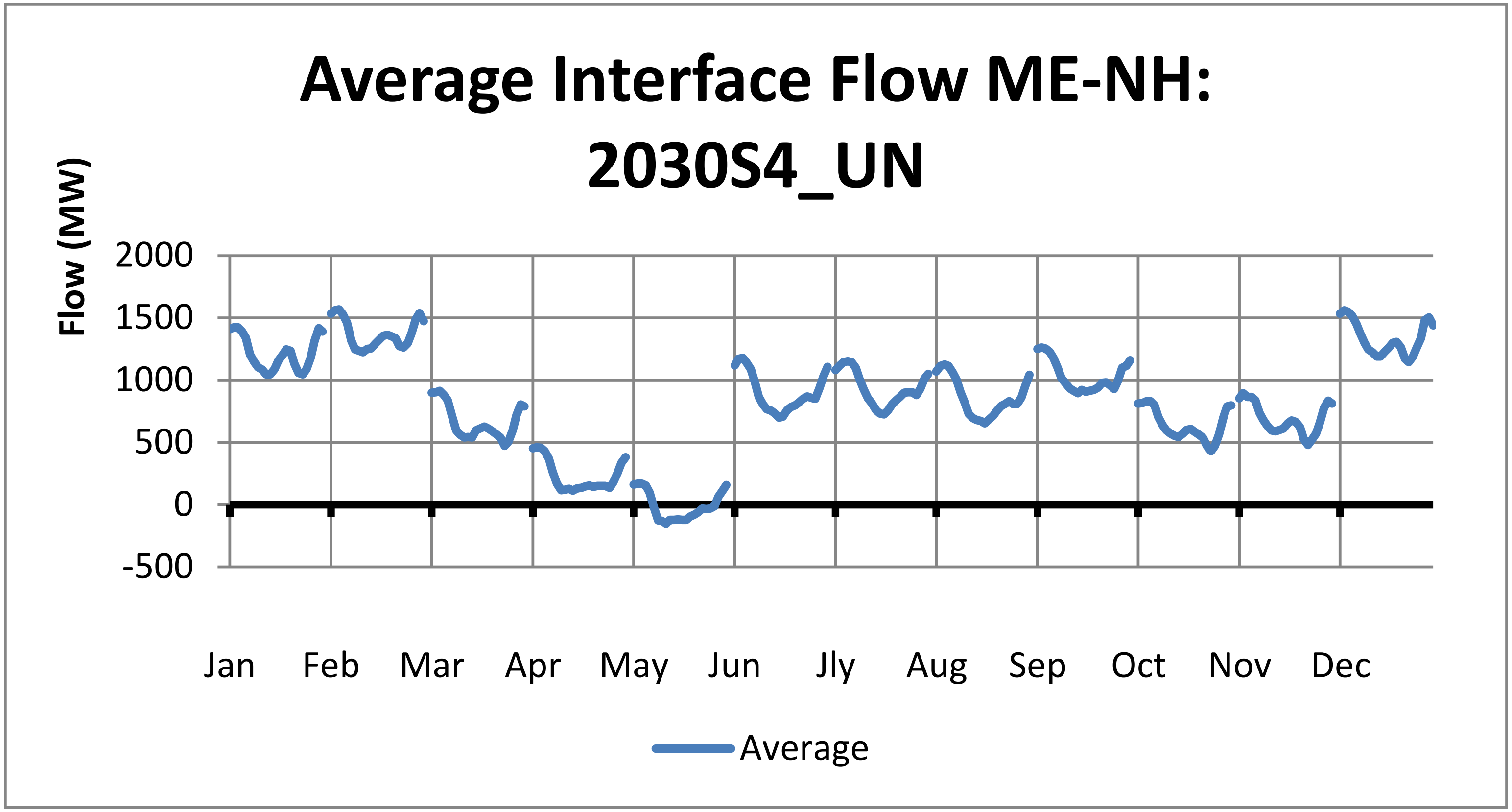
Diurnal Interface Flow: ME-NH
2030 Unconstrained Scenario 2



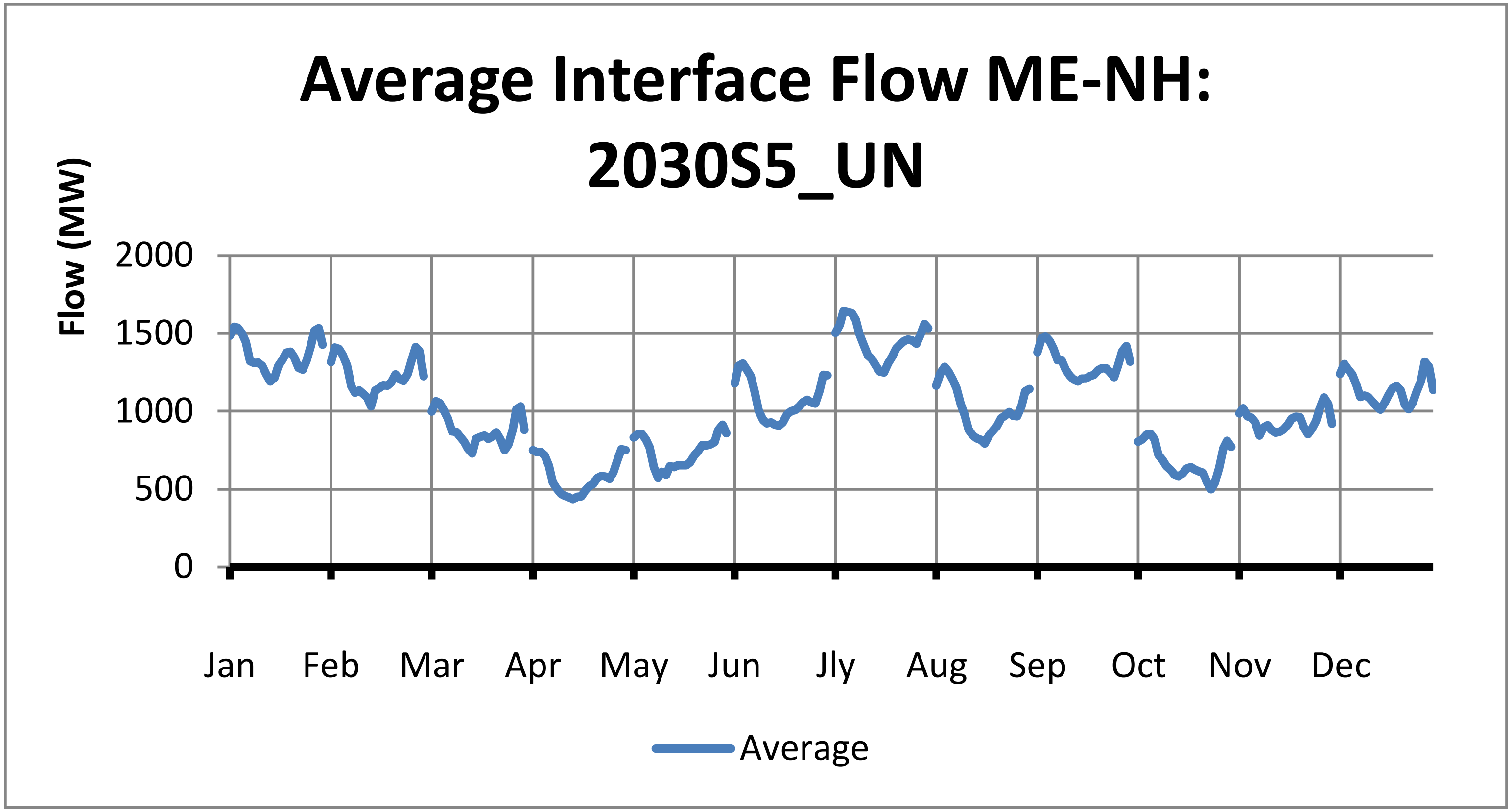
Diurnal Interface Flow: ME-NH 2030 Unconstrained Scenario 3



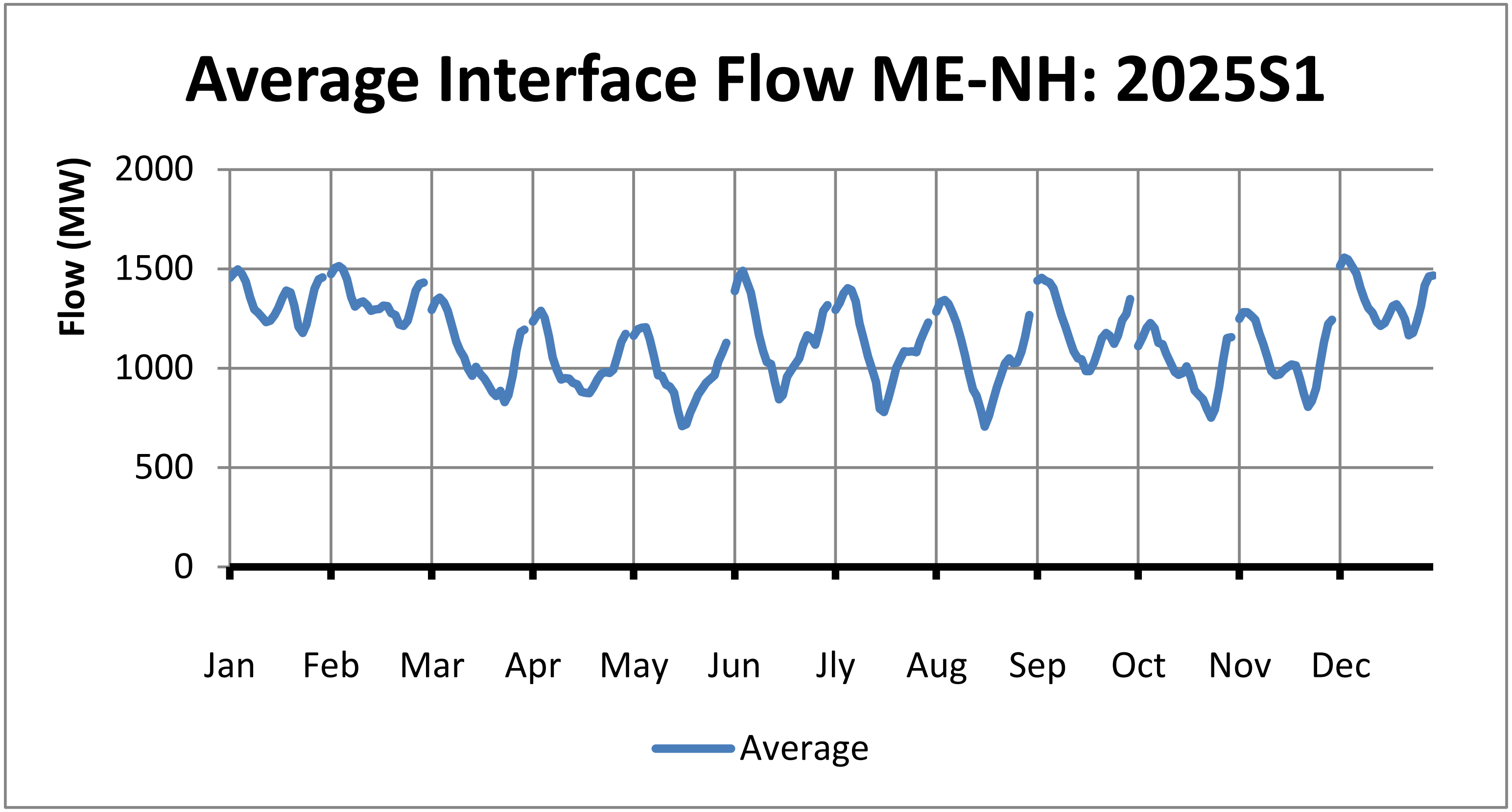
Diurnal Interface Flow: ME-NH 2030 Unconstrained Scenario 4



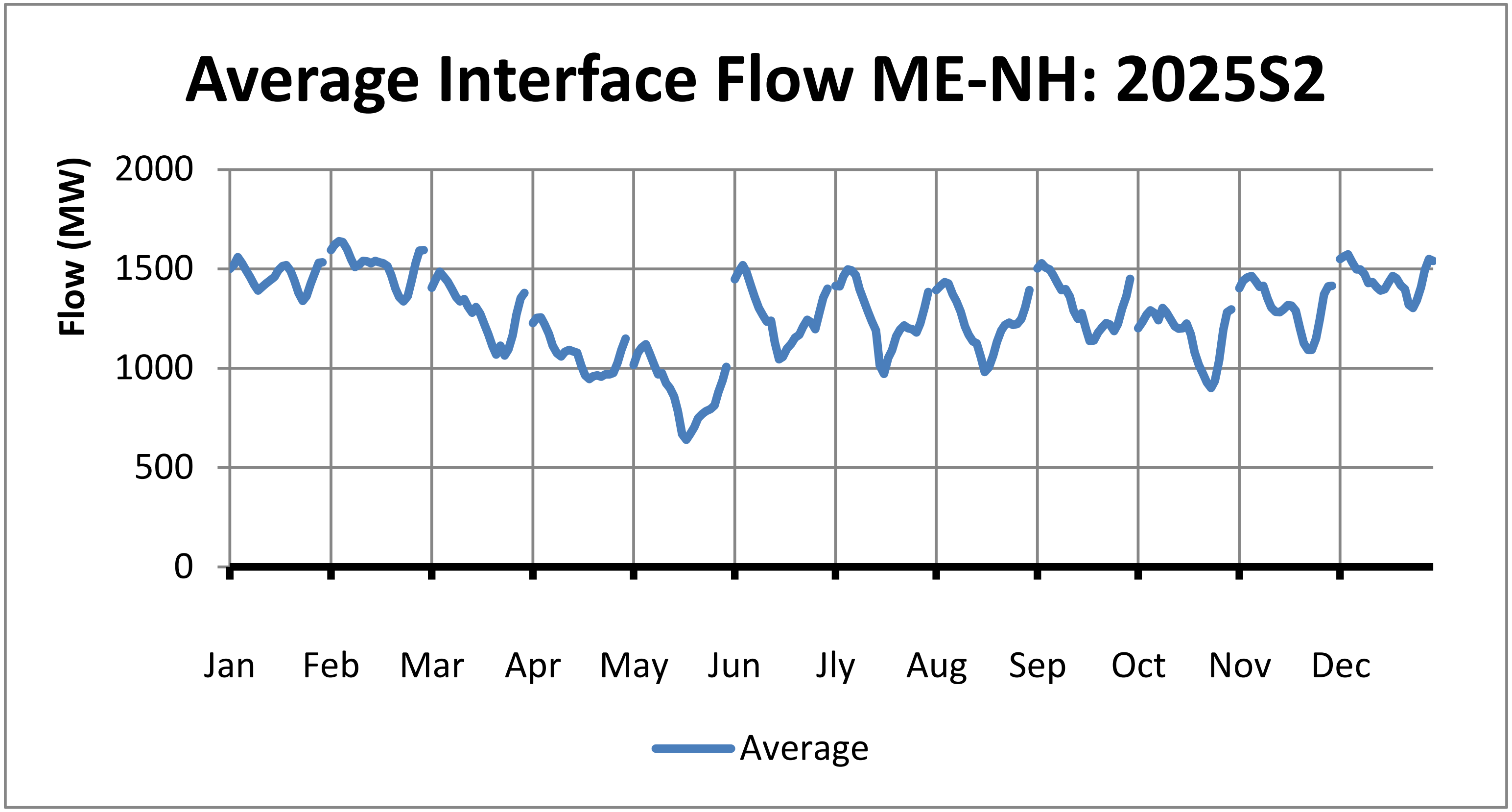
Diurnal Interface Flow: ME-NH
2030 Unconstrained Scenario 5



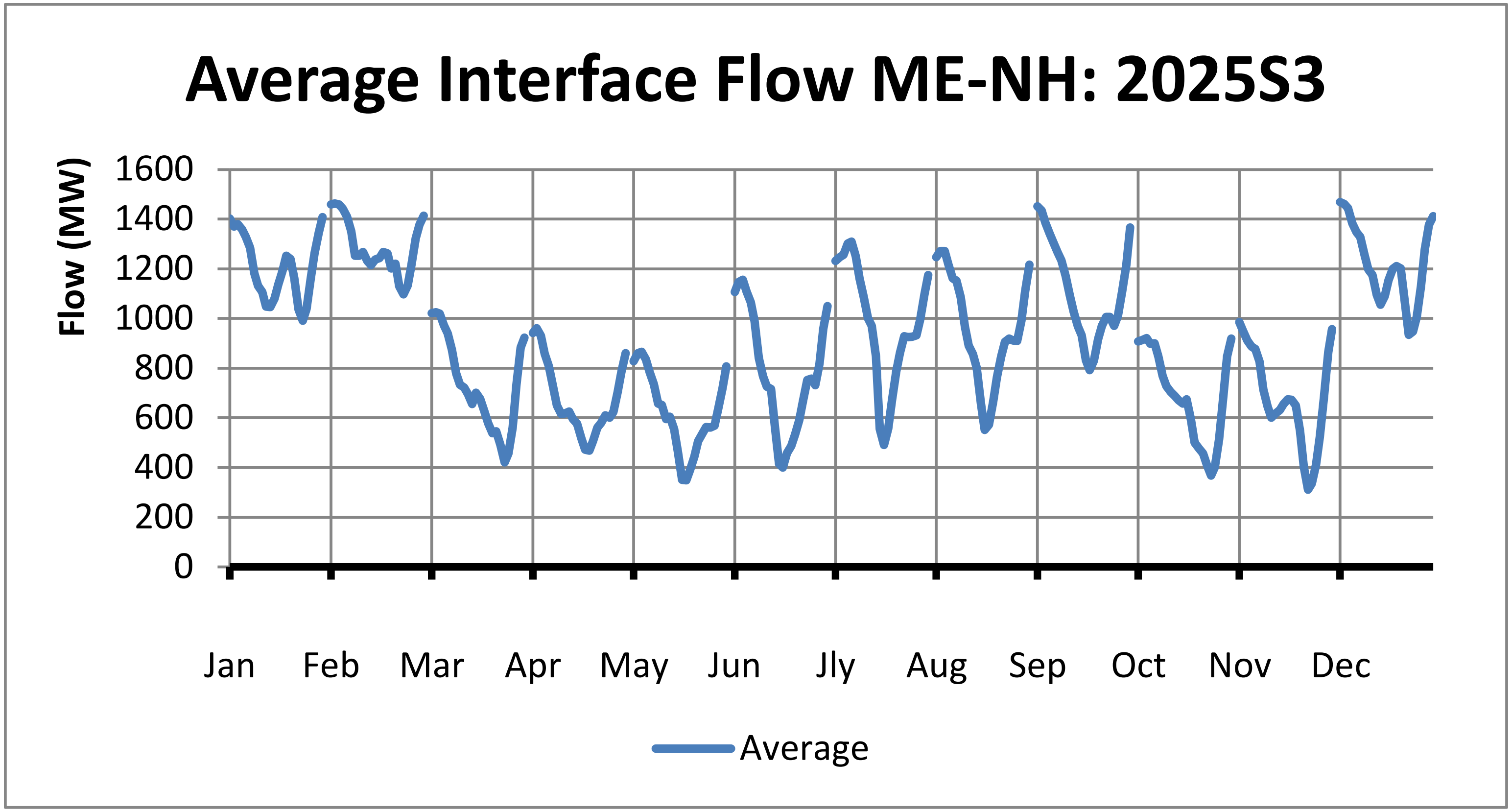
Diurnal Interface Flow: ME-NH
2025 Constrained Scenario 1



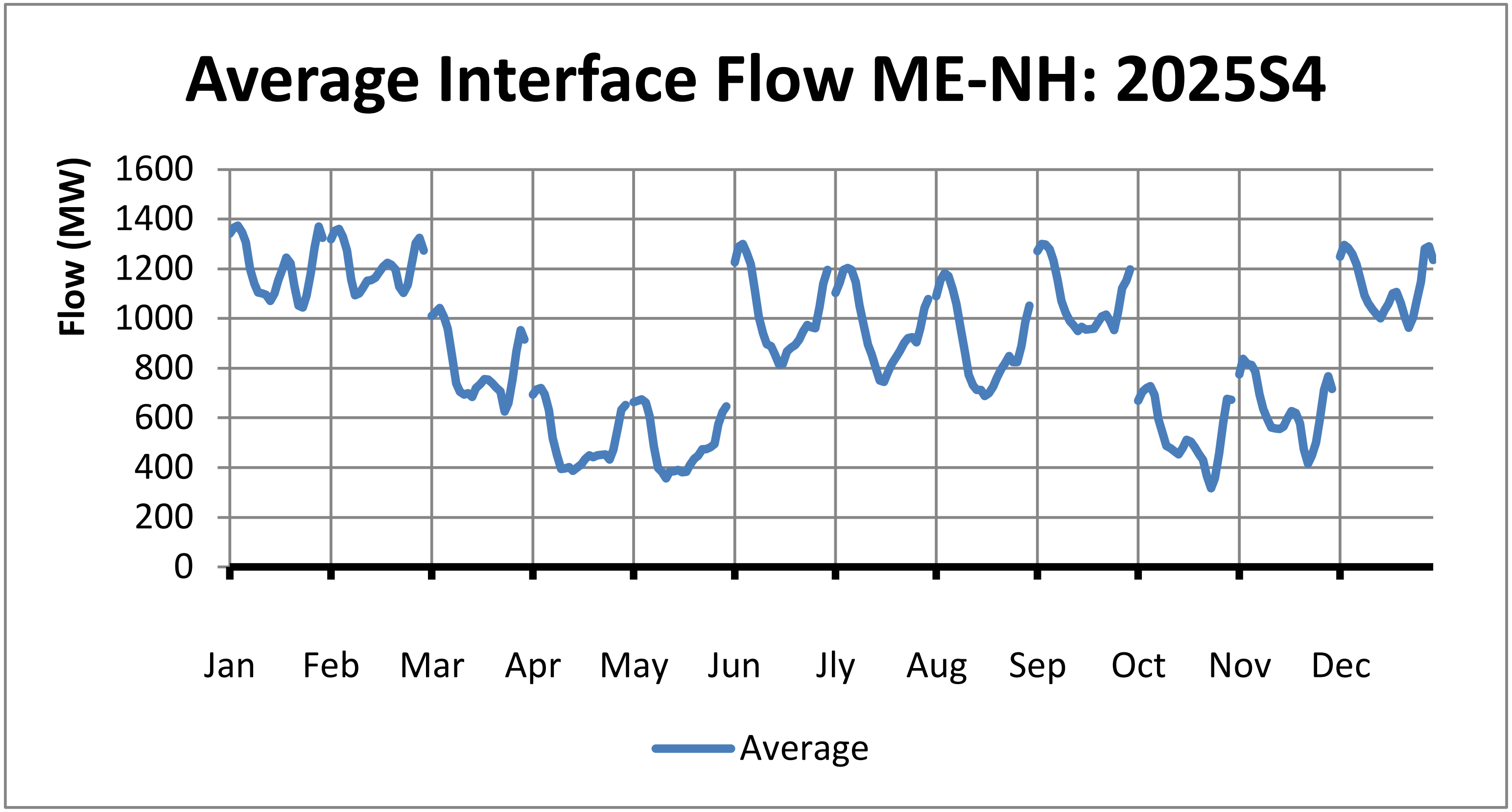
Diurnal Interface Flow: ME-NH
2025 Unconstrained Scenario 2



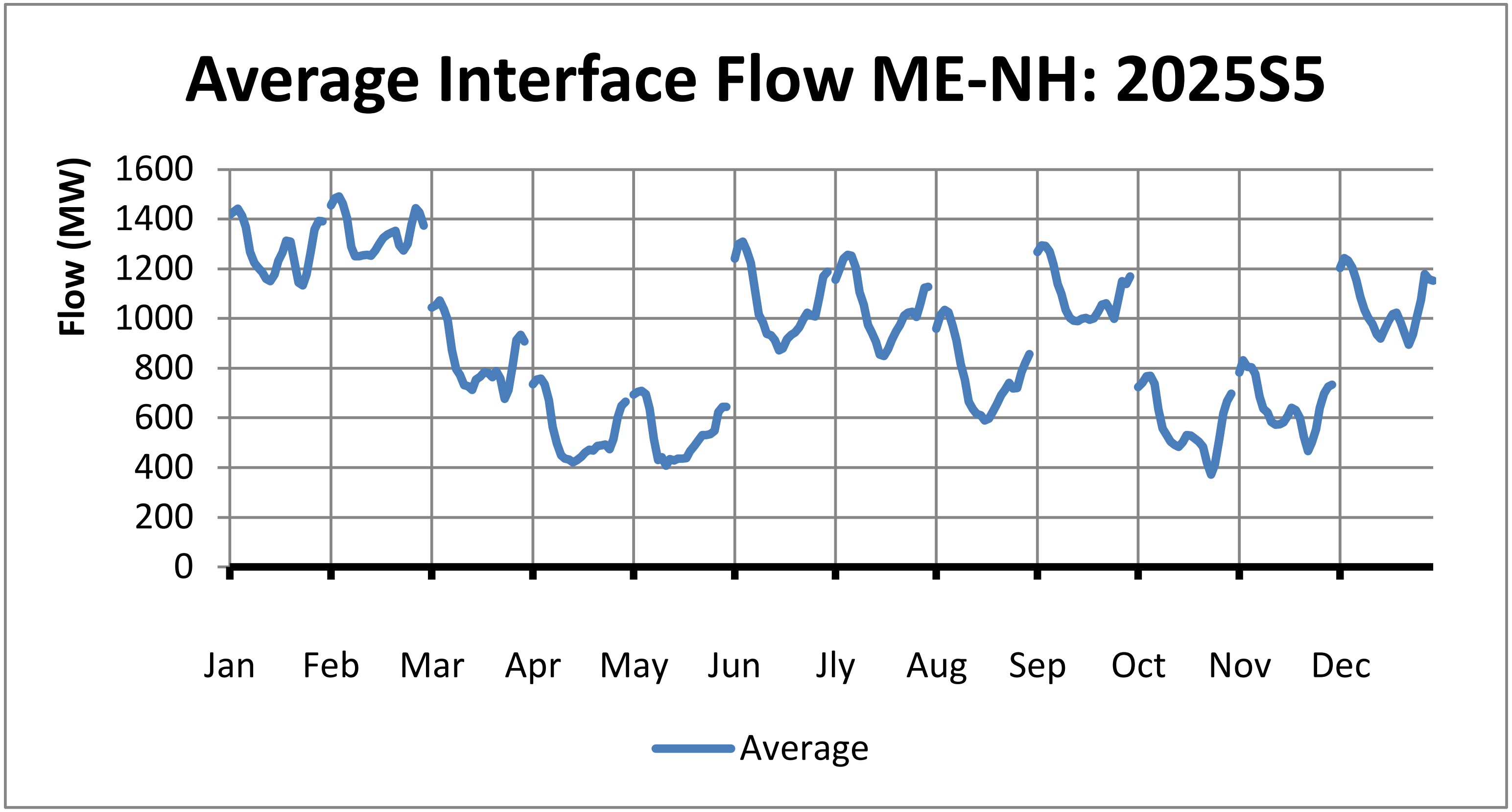
Diurnal Interface Flow: ME-NH
2025 Unconstrained Scenario 3



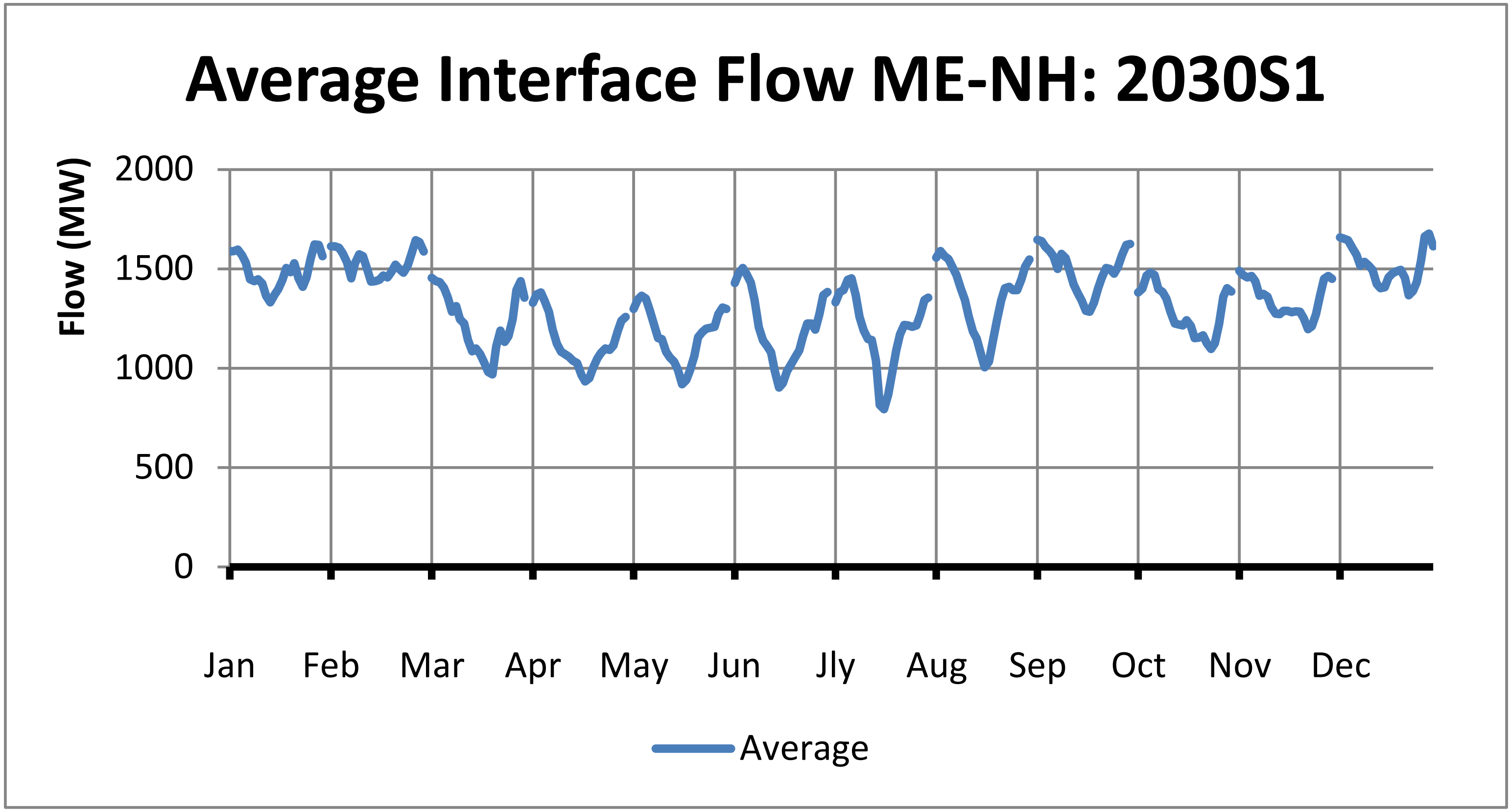
Diurnal Interface Flow: ME-NH 2025 Unconstrained Scenario 4



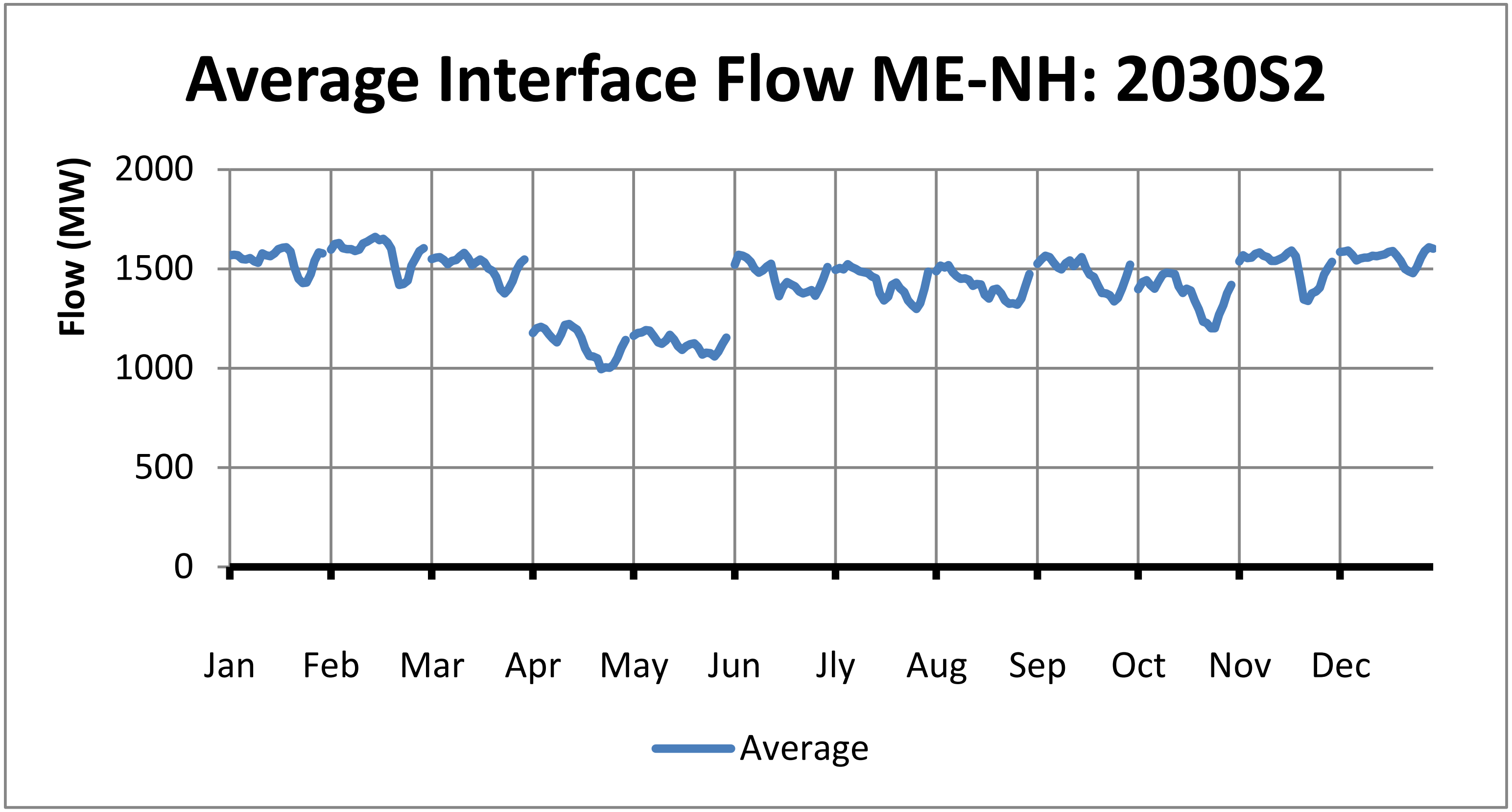
Diurnal Interface Flow: ME-NH 2025 Unconstrained Scenario 5



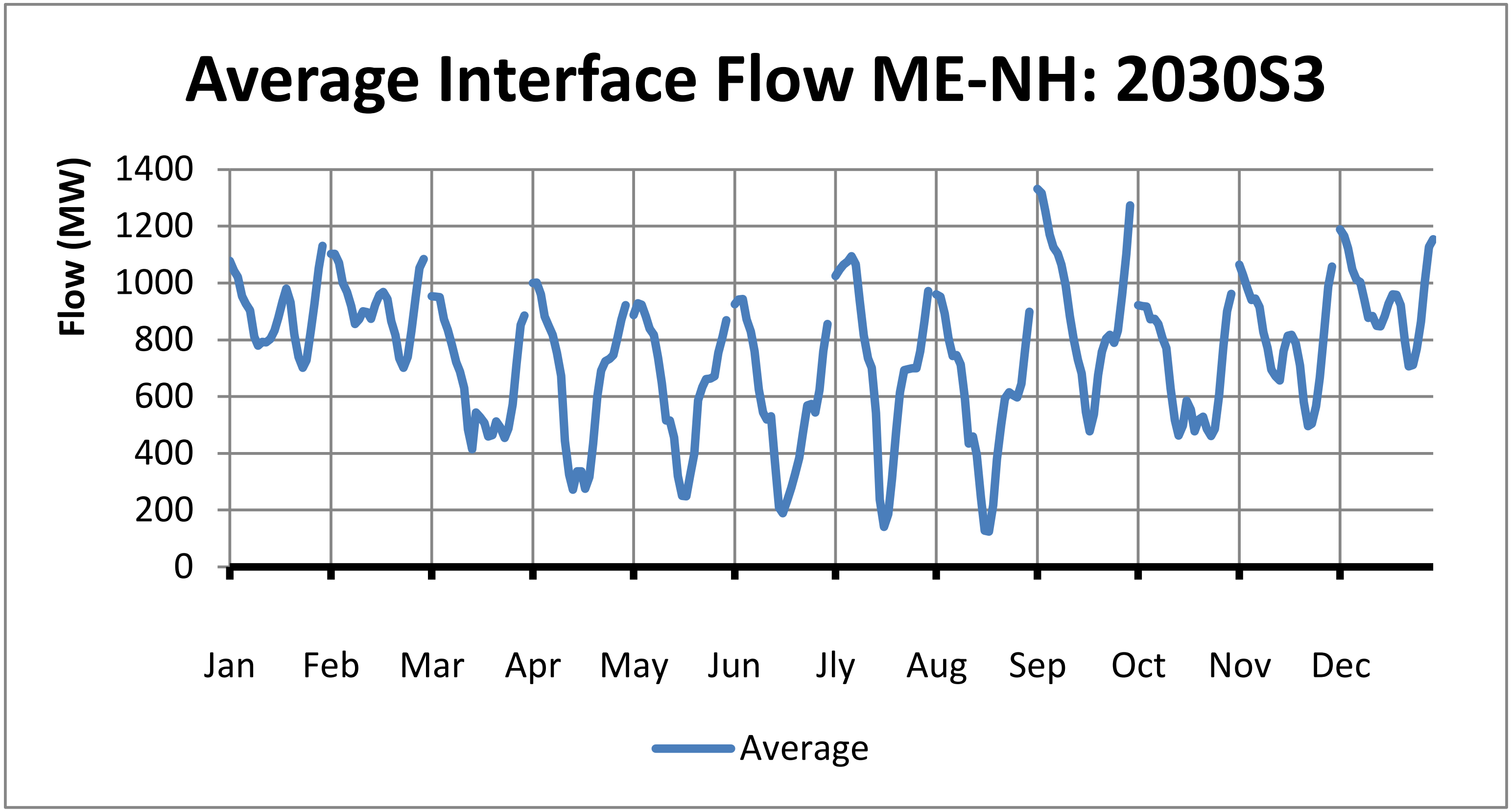
Diurnal Interface Flow: ME-NH 2030 Unconstrained Scenario 1



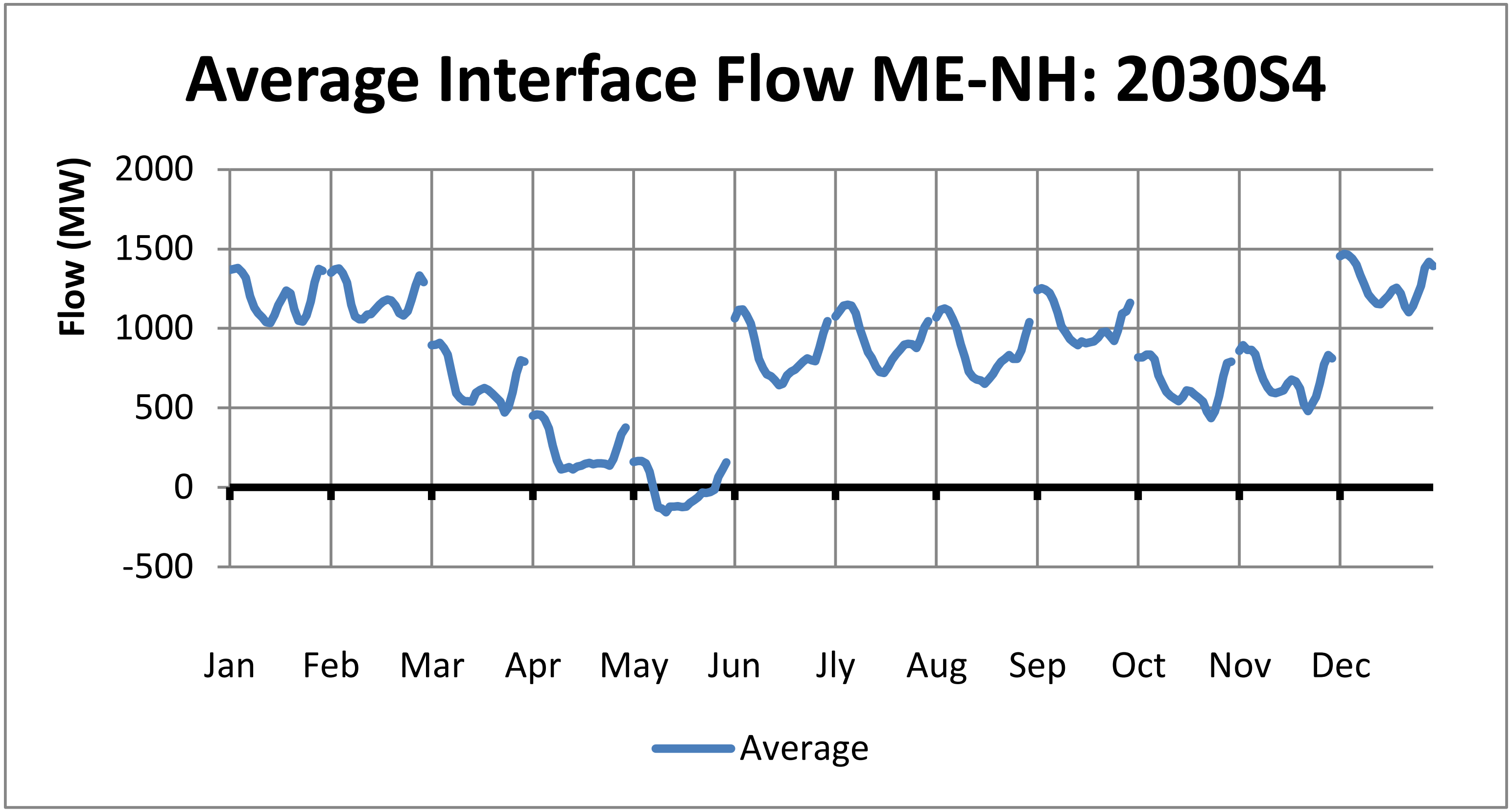
Diurnal Interface Flow: ME-NH
2030 Unconstrained Scenario 2



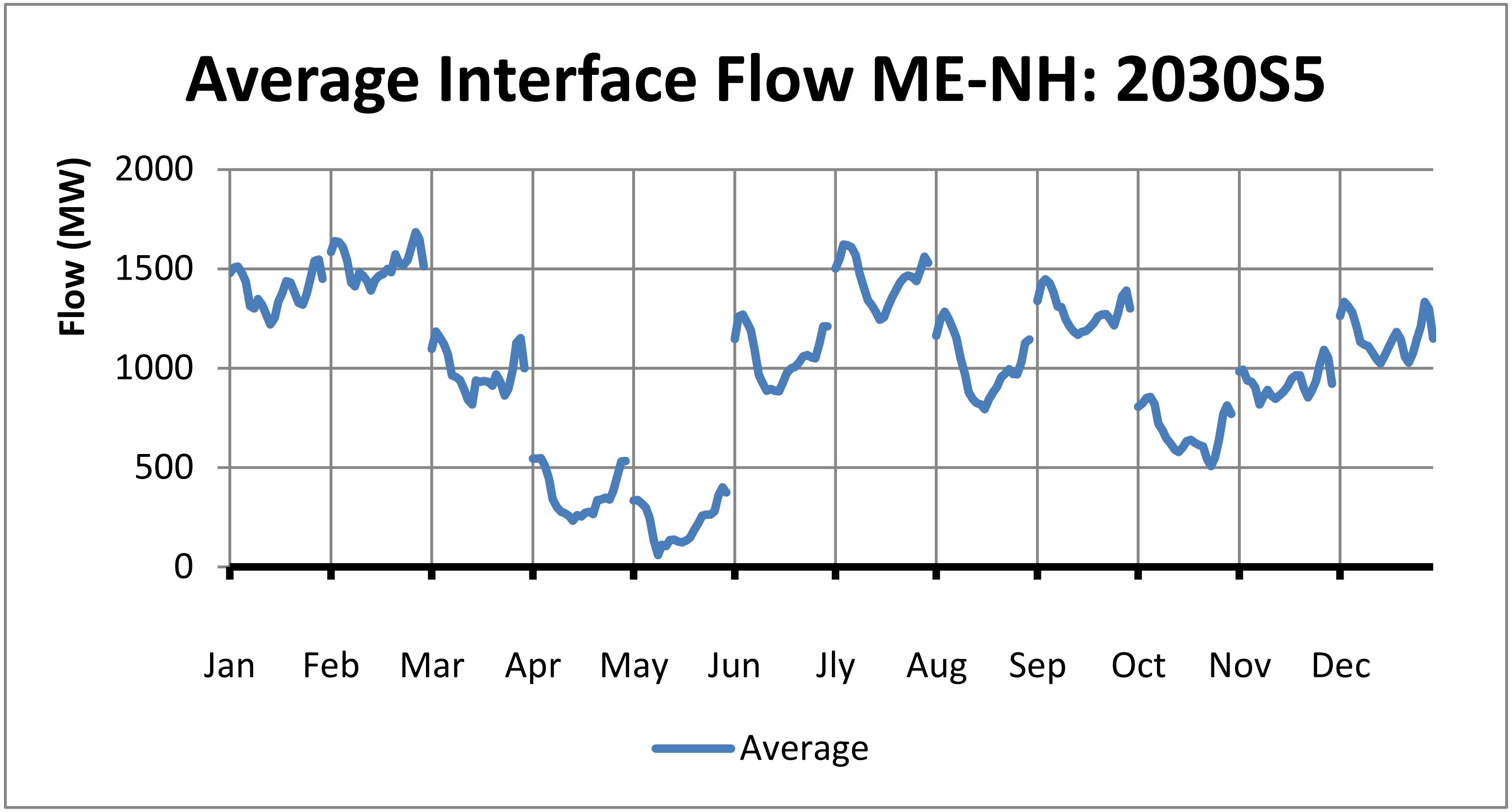
Diurnal Interface Flow: ME-NH
2030 Unconstrained Scenario 3



Diurnal Interface Flow: ME-NH
2030 Unconstrained Scenario 4



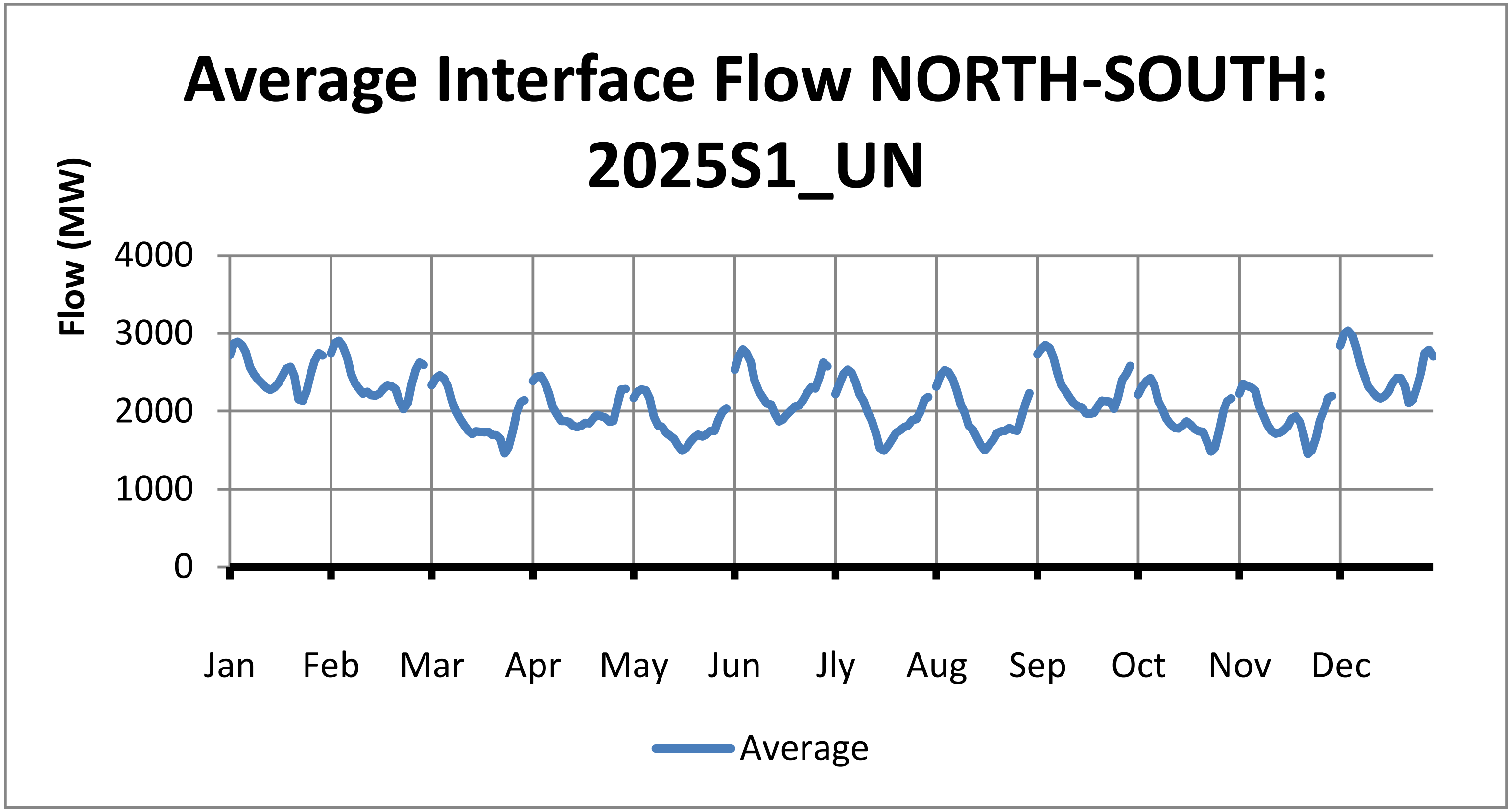
Diurnal Interface Flow: ME-NH
2030 Unconstrained Scenario 5



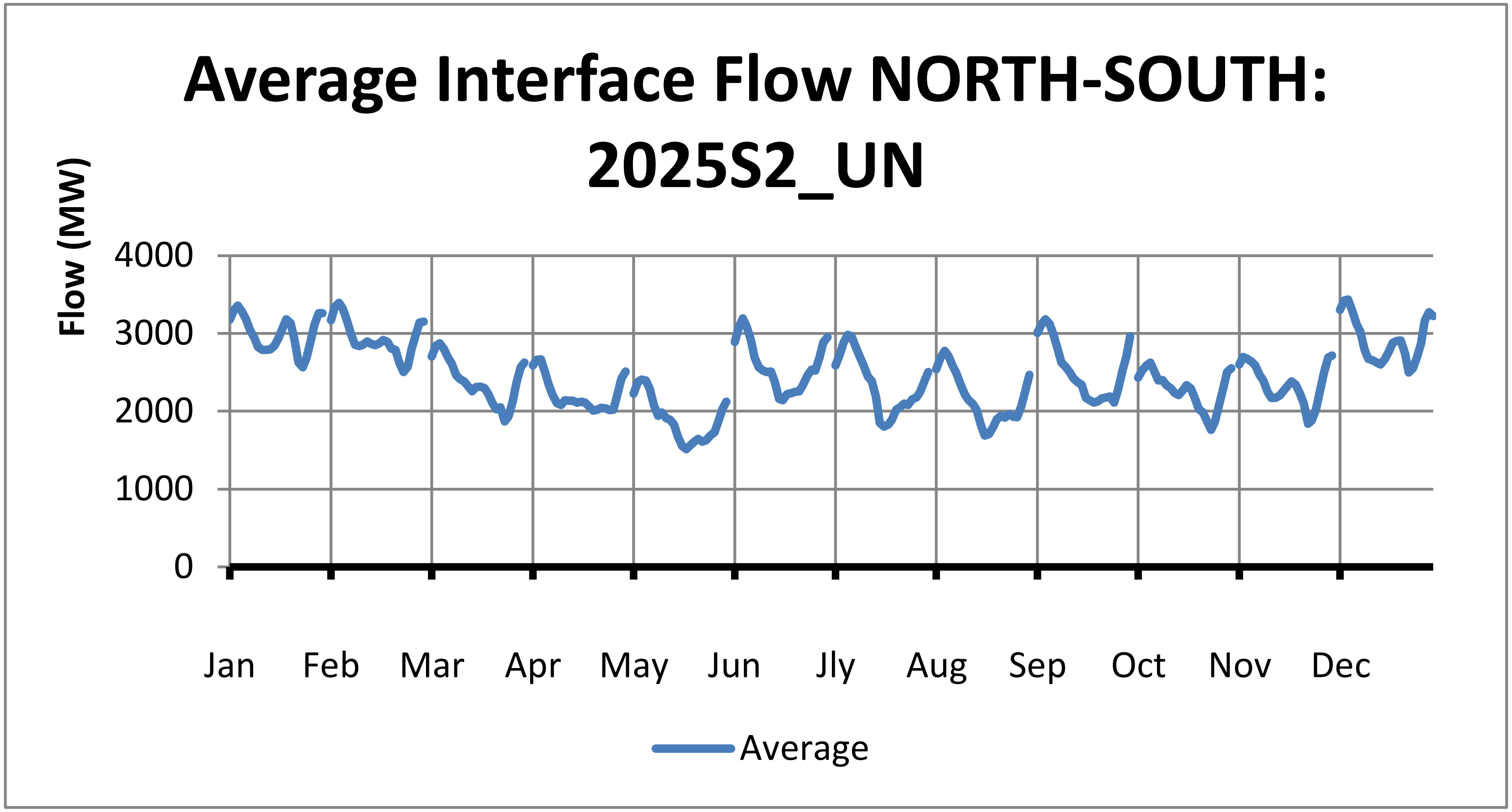
DIURNAL FLOWS ACROSS INTERFACES 2025 AND 2030

North South Interface

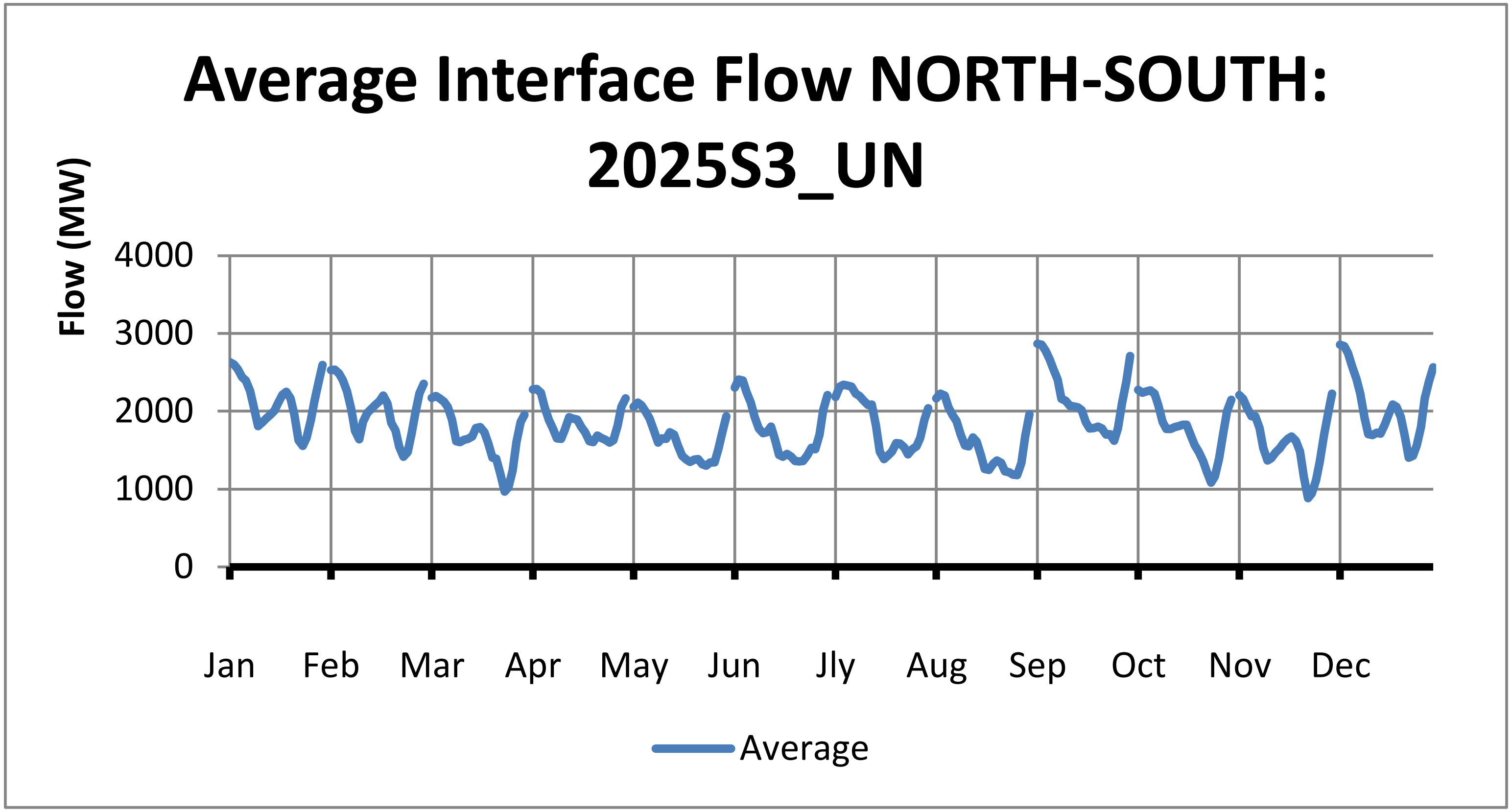
Diurnal Interface Flow: North-South 2025 Unconstrained Scenario 1



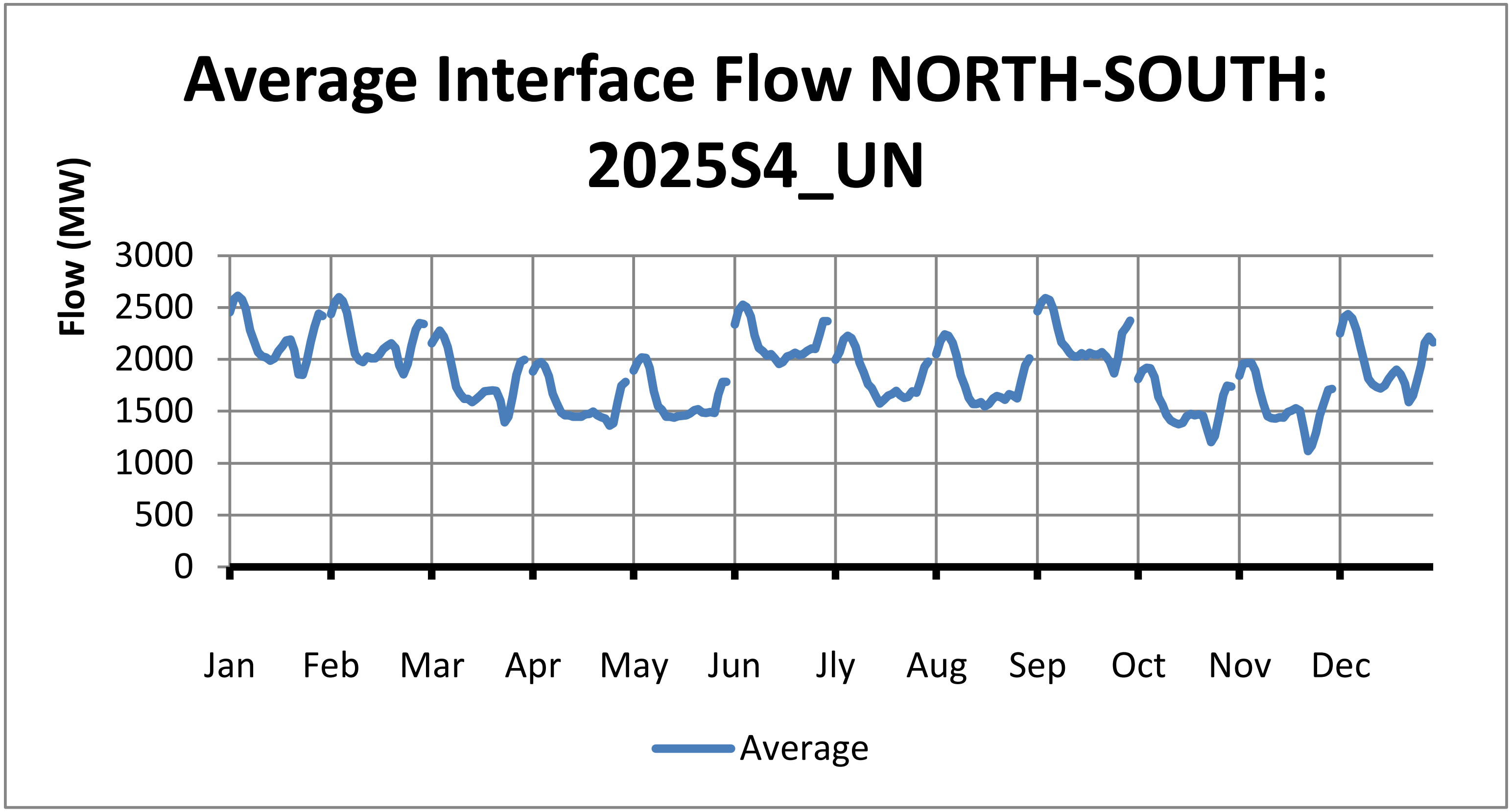
Diurnal Interface Flow: North-South 2025 Unconstrained Scenario 2



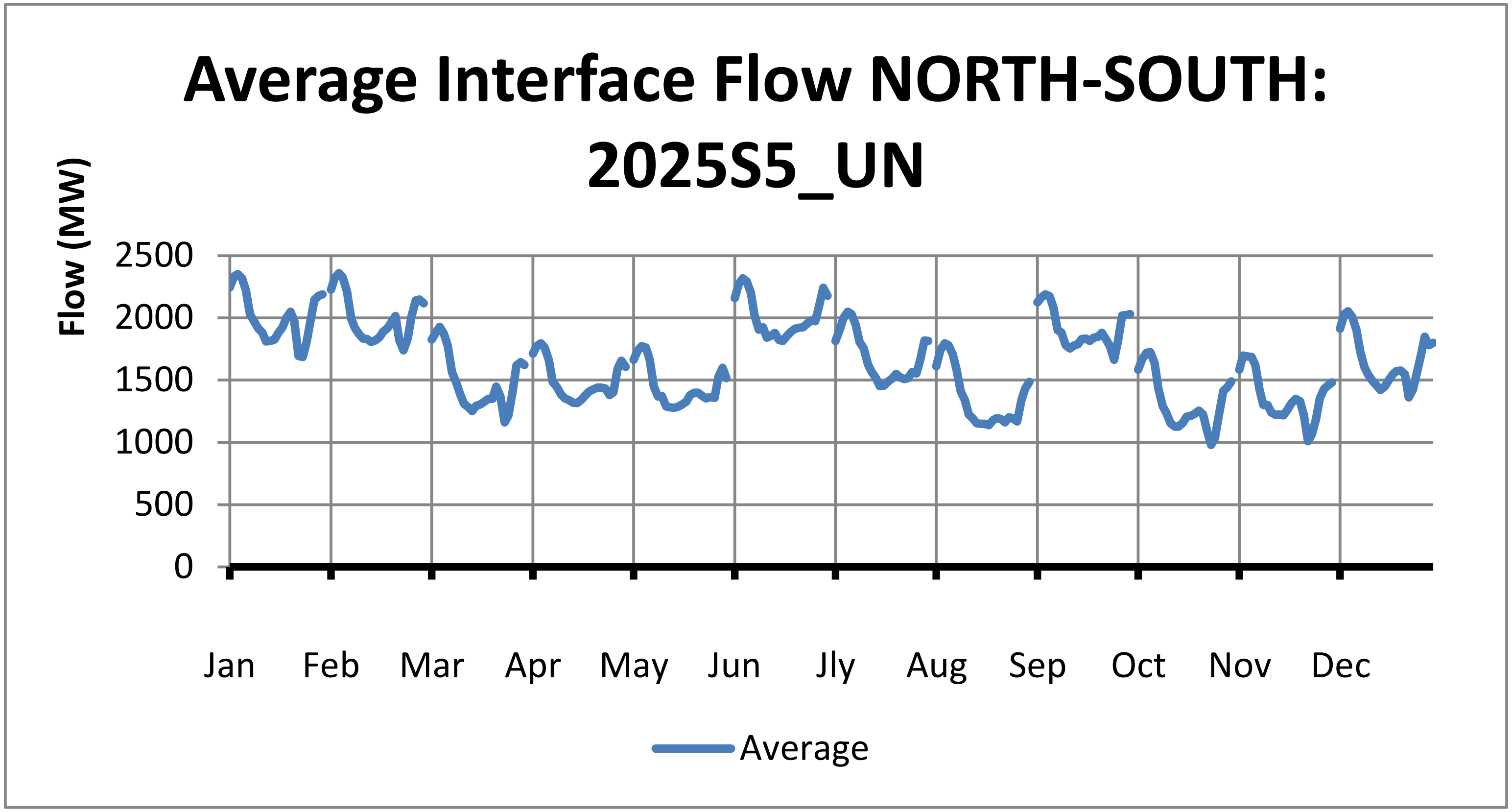
Diurnal Interface Flow: North-South 2025 Unconstrained Scenario 3



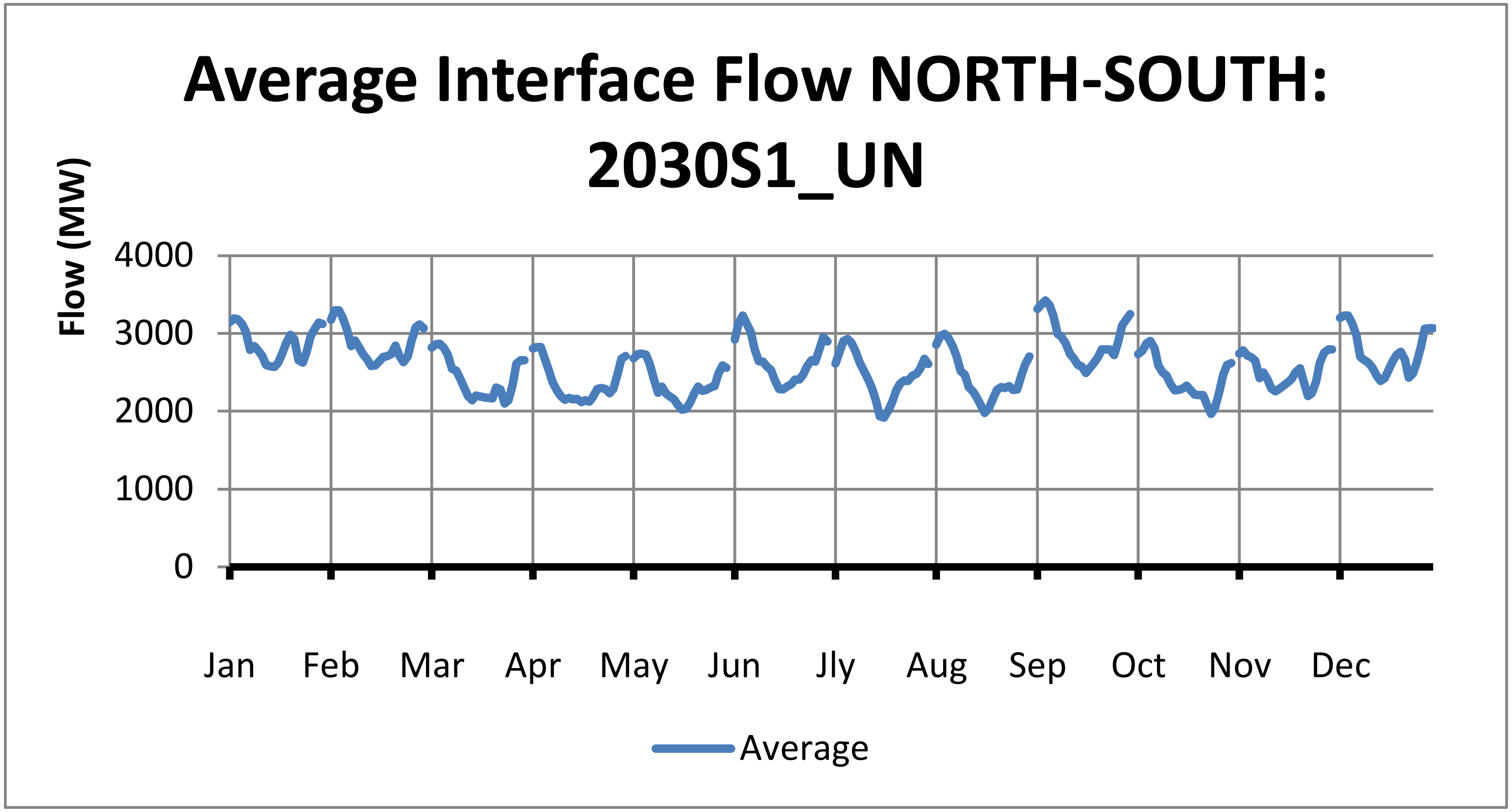
Diurnal Interface Flow: North-South 2025 Unconstrained Scenario 4



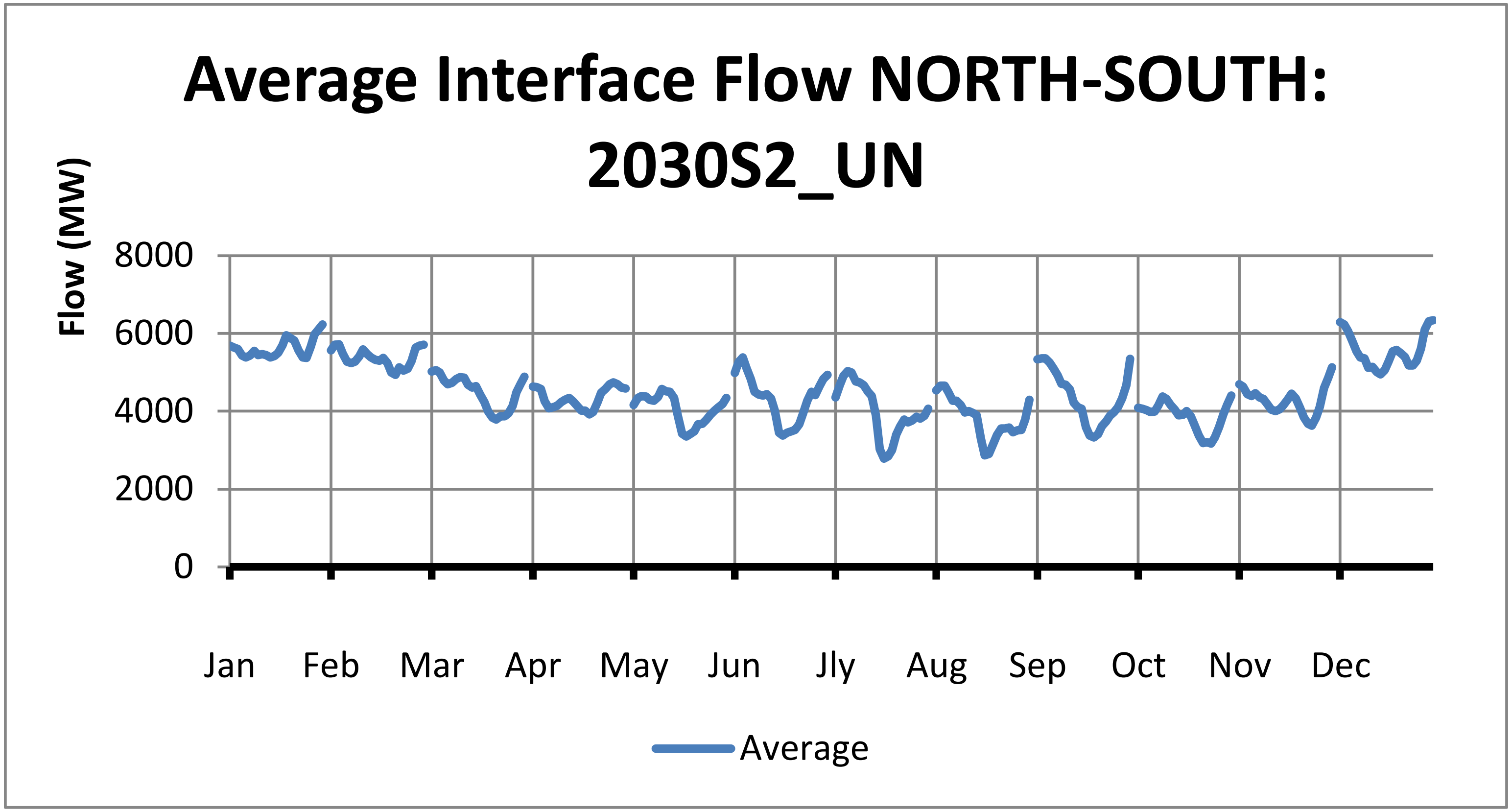
Diurnal Interface Flow: North-South 2025 Unconstrained Scenario 5



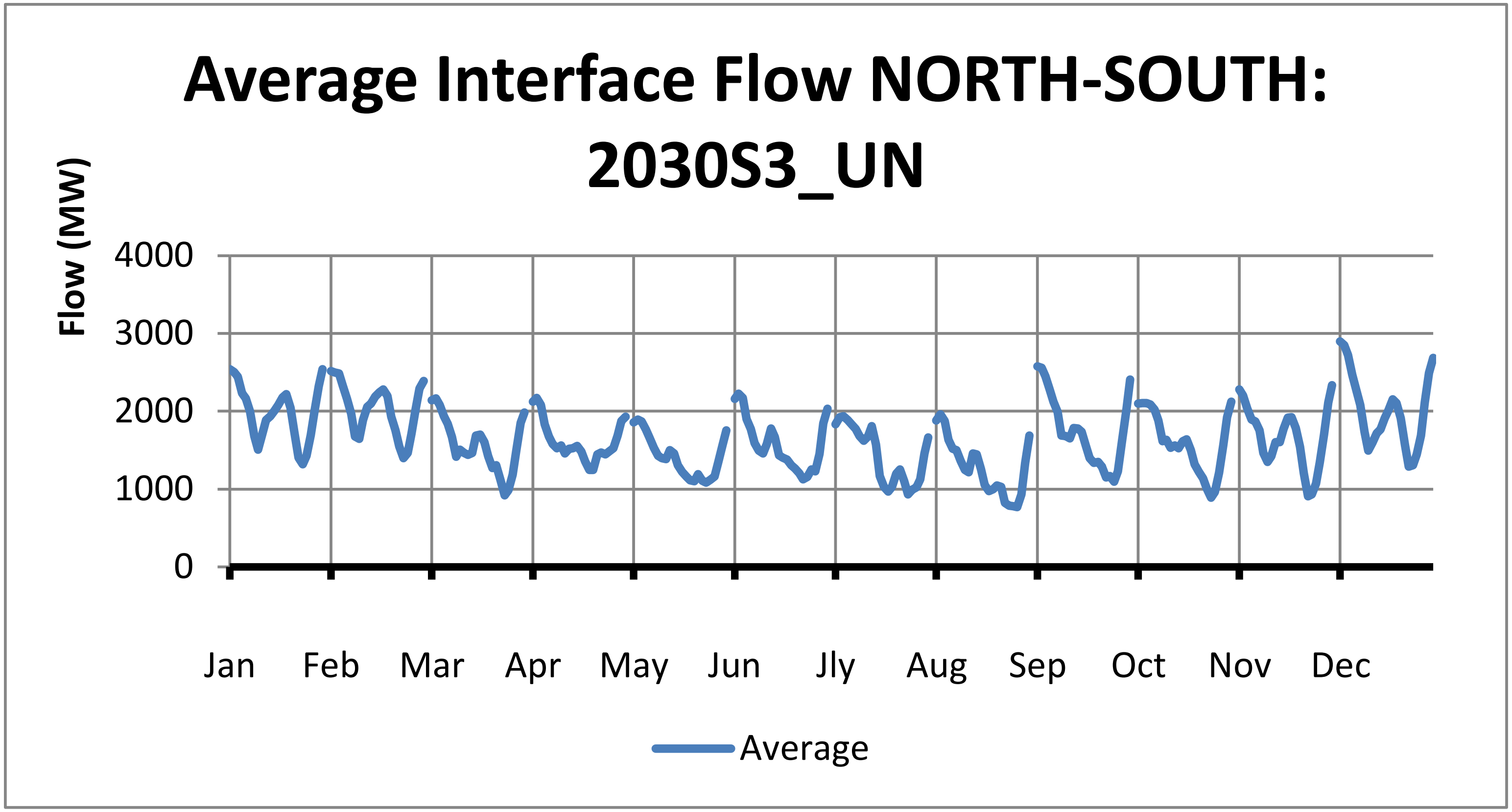
Diurnal Interface Flow: North-South 2030 Unconstrained Scenario 1



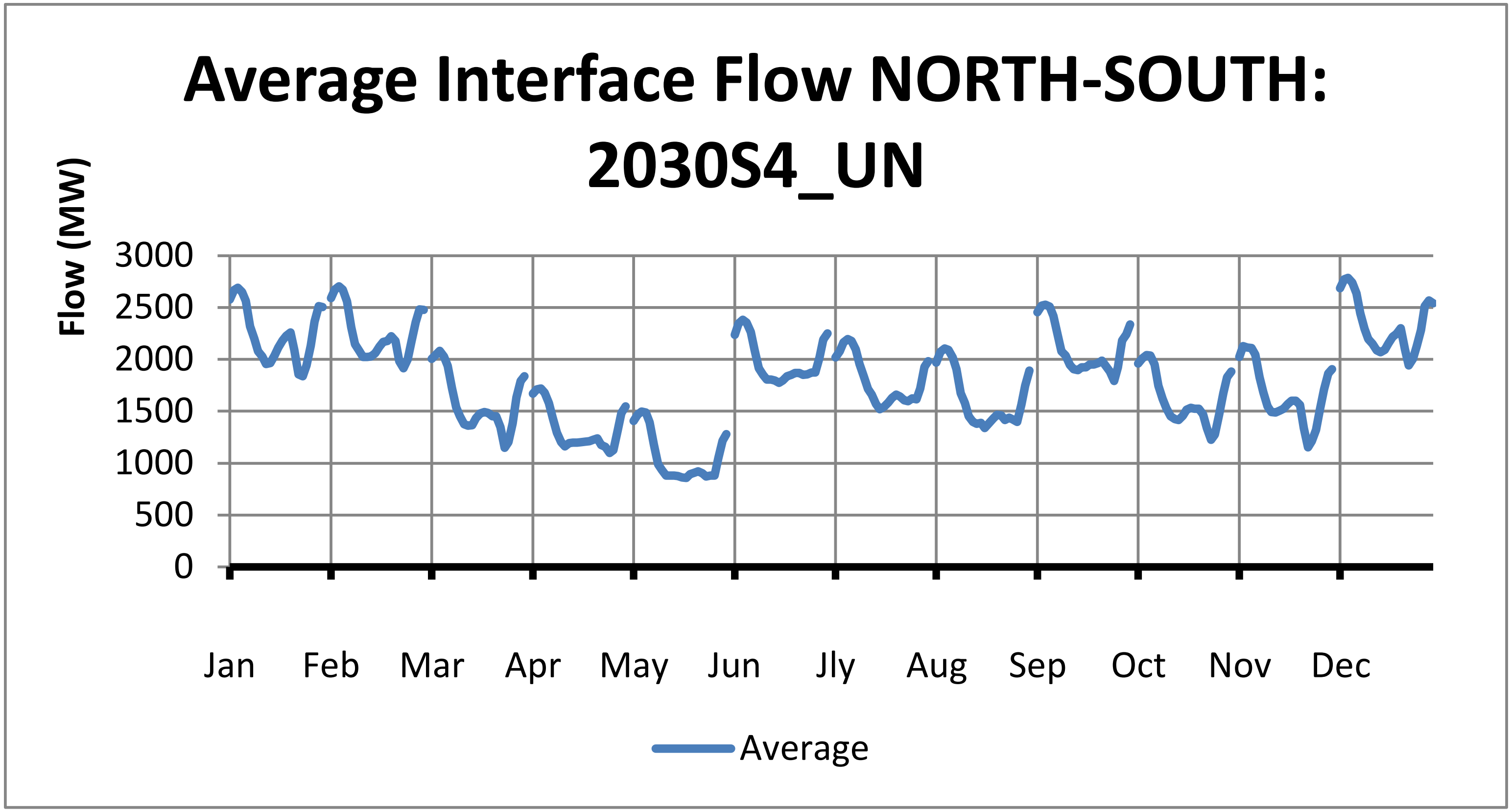
Diurnal Interface Flow: North-South 2030 Unconstrained Scenario 2



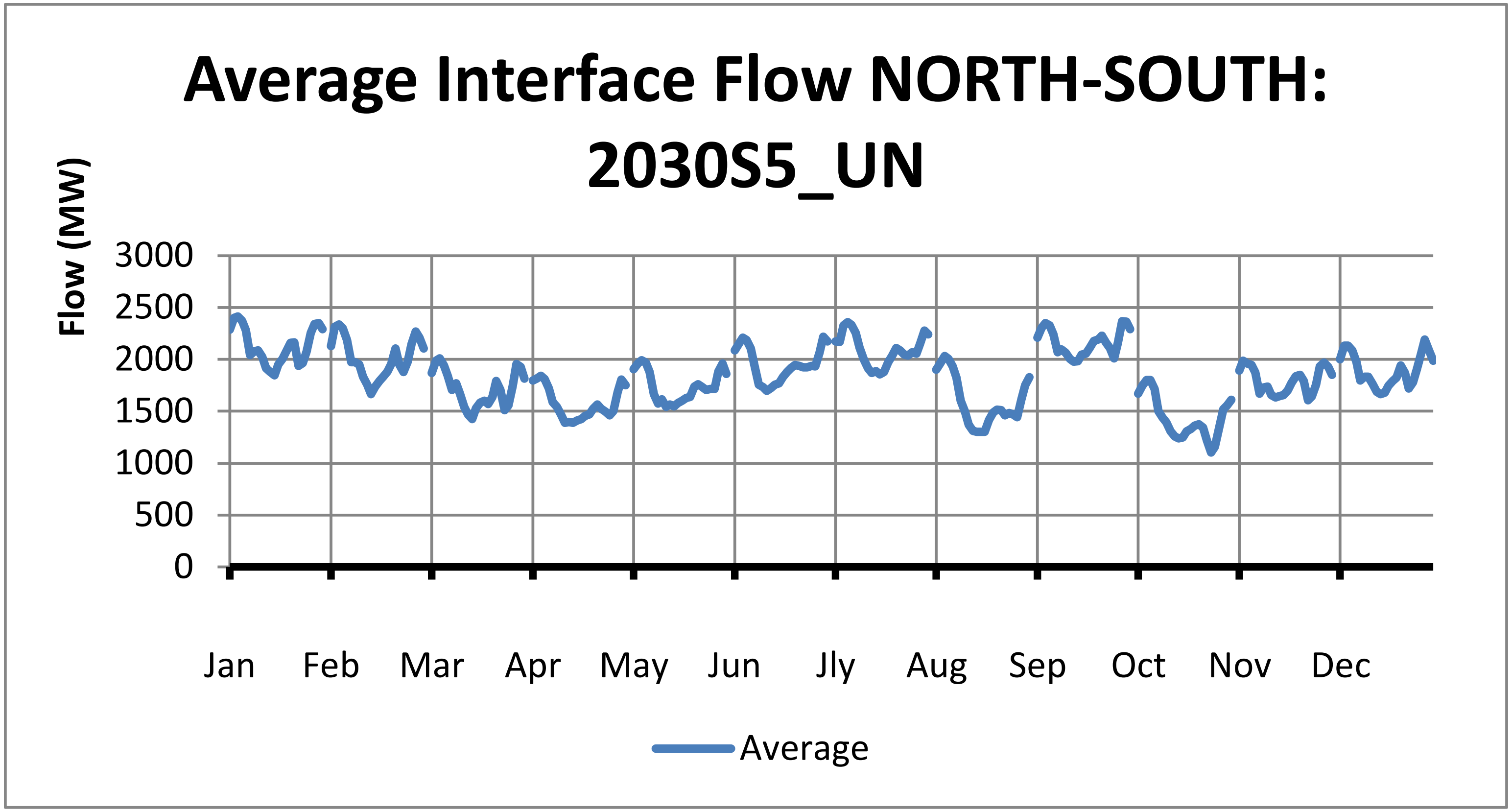
Diurnal Interface Flow: North-South 2030 Unconstrained Scenario 3



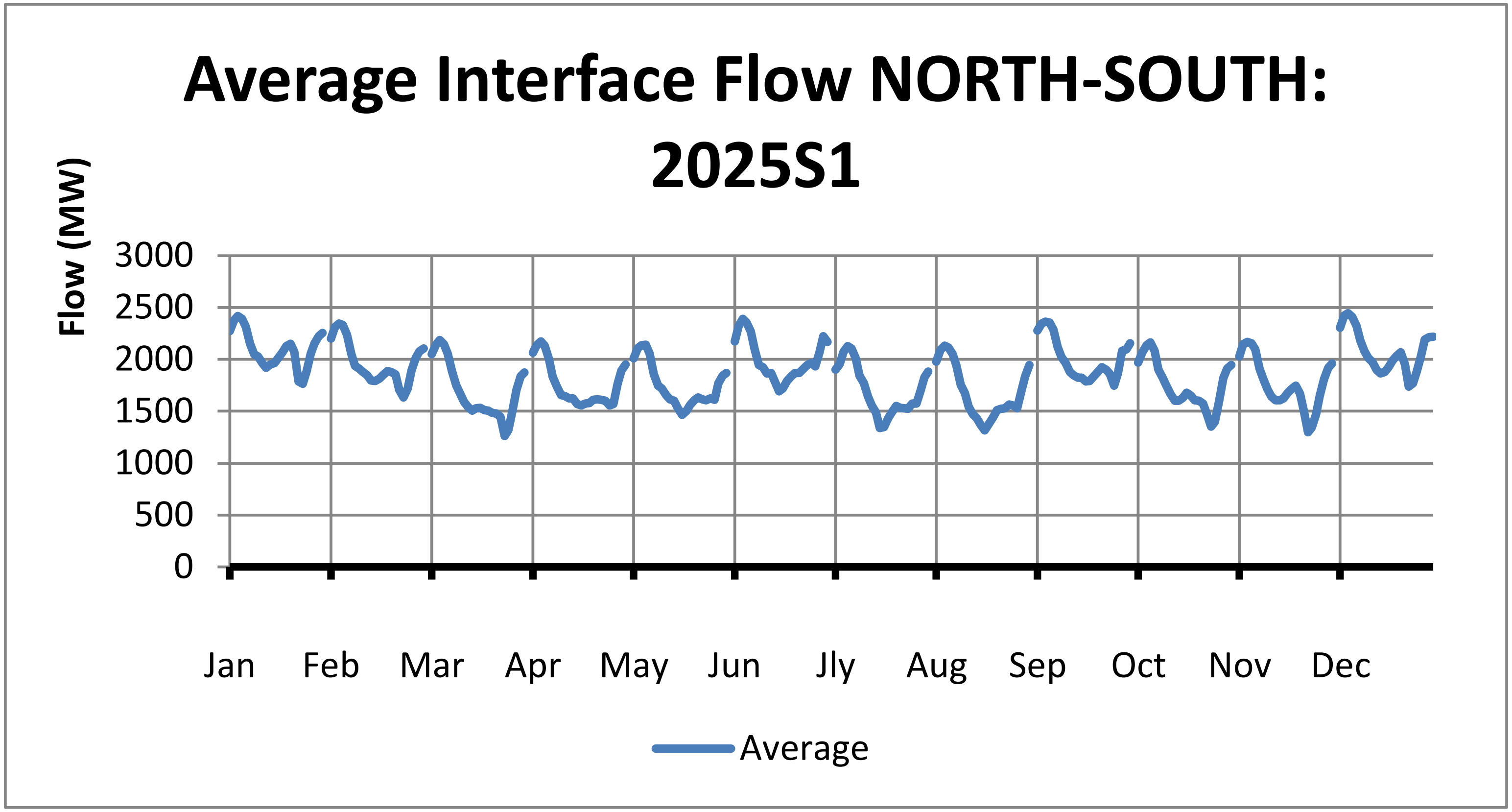
Diurnal Interface Flow: North-South 2030 Unconstrained Scenario 4



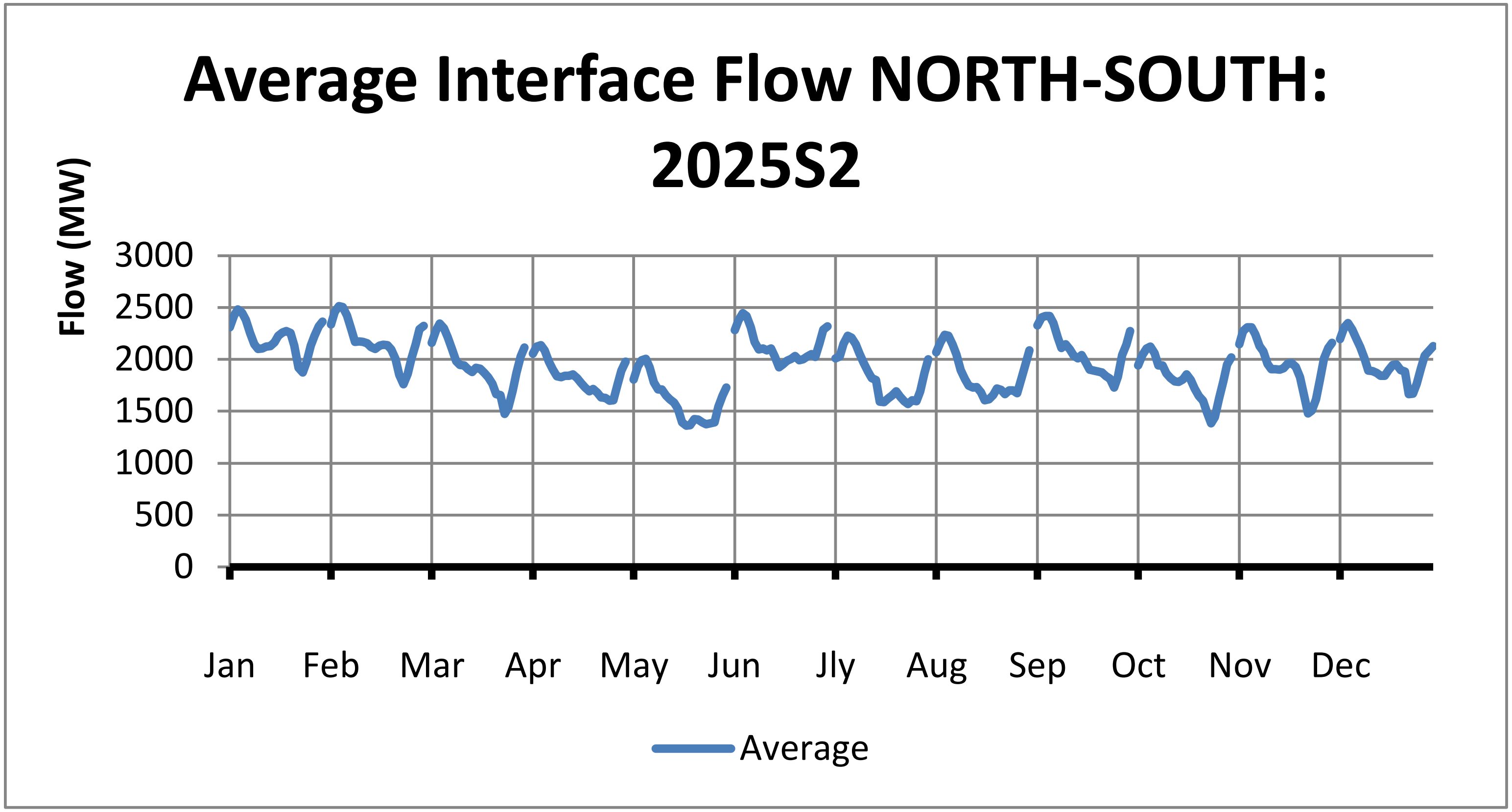
Diurnal Interface Flow: North-South 2030 Unconstrained Scenario 5



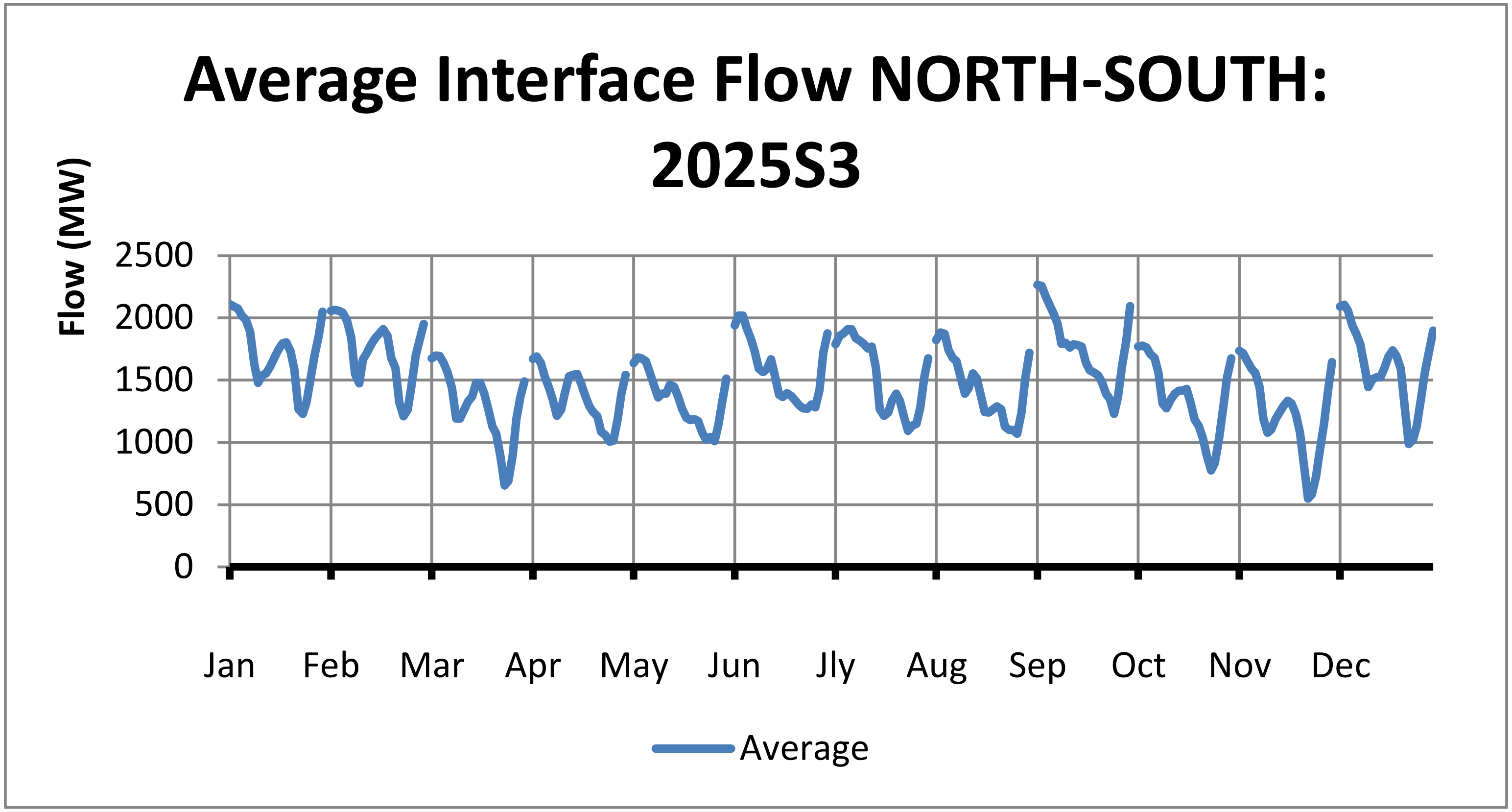
Diurnal Interface Flow: North-South 2025 Constrained Scenario 1



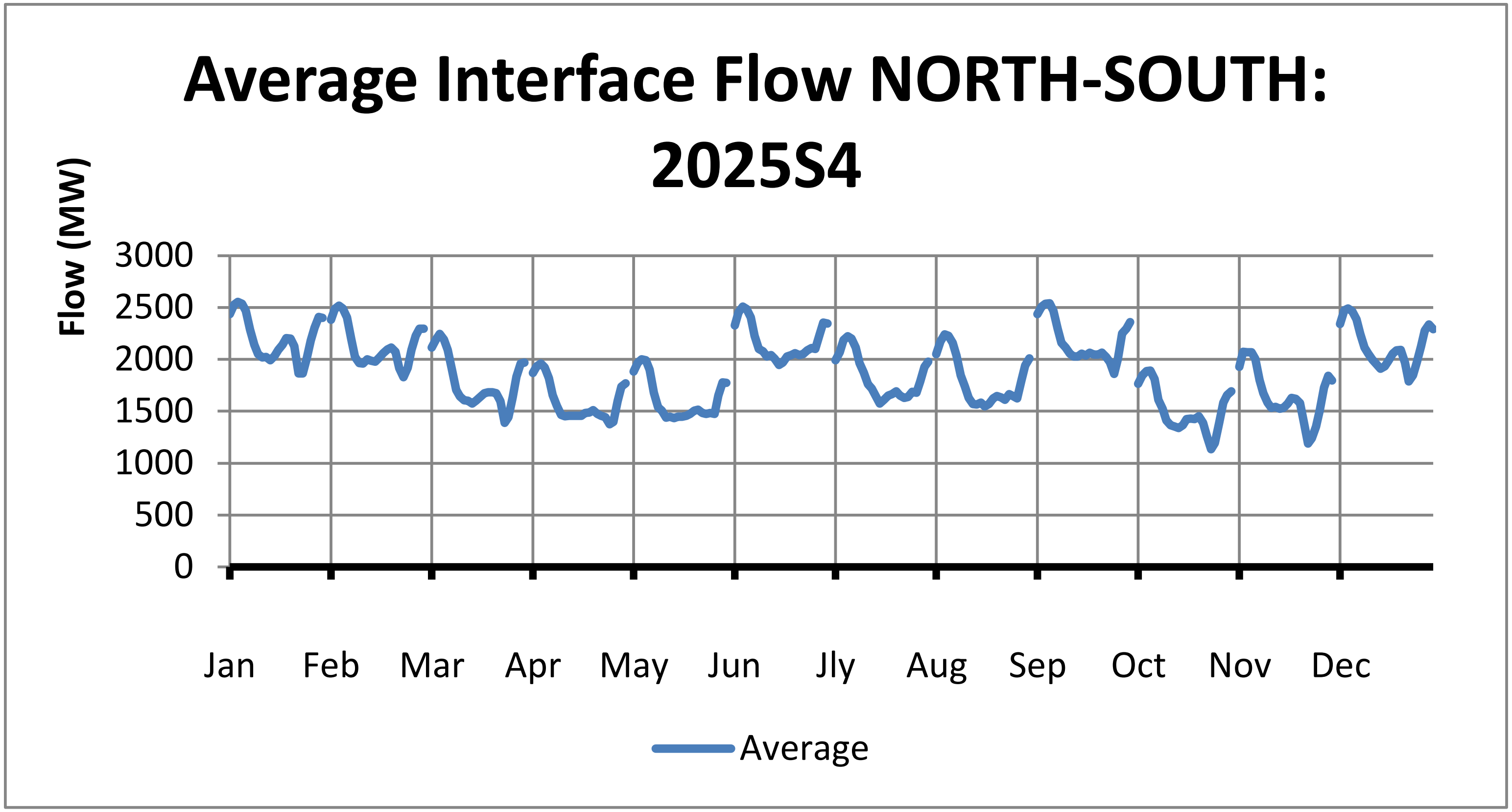
Diurnal Interface Flow: North-South 2025 Constrained Scenario 2



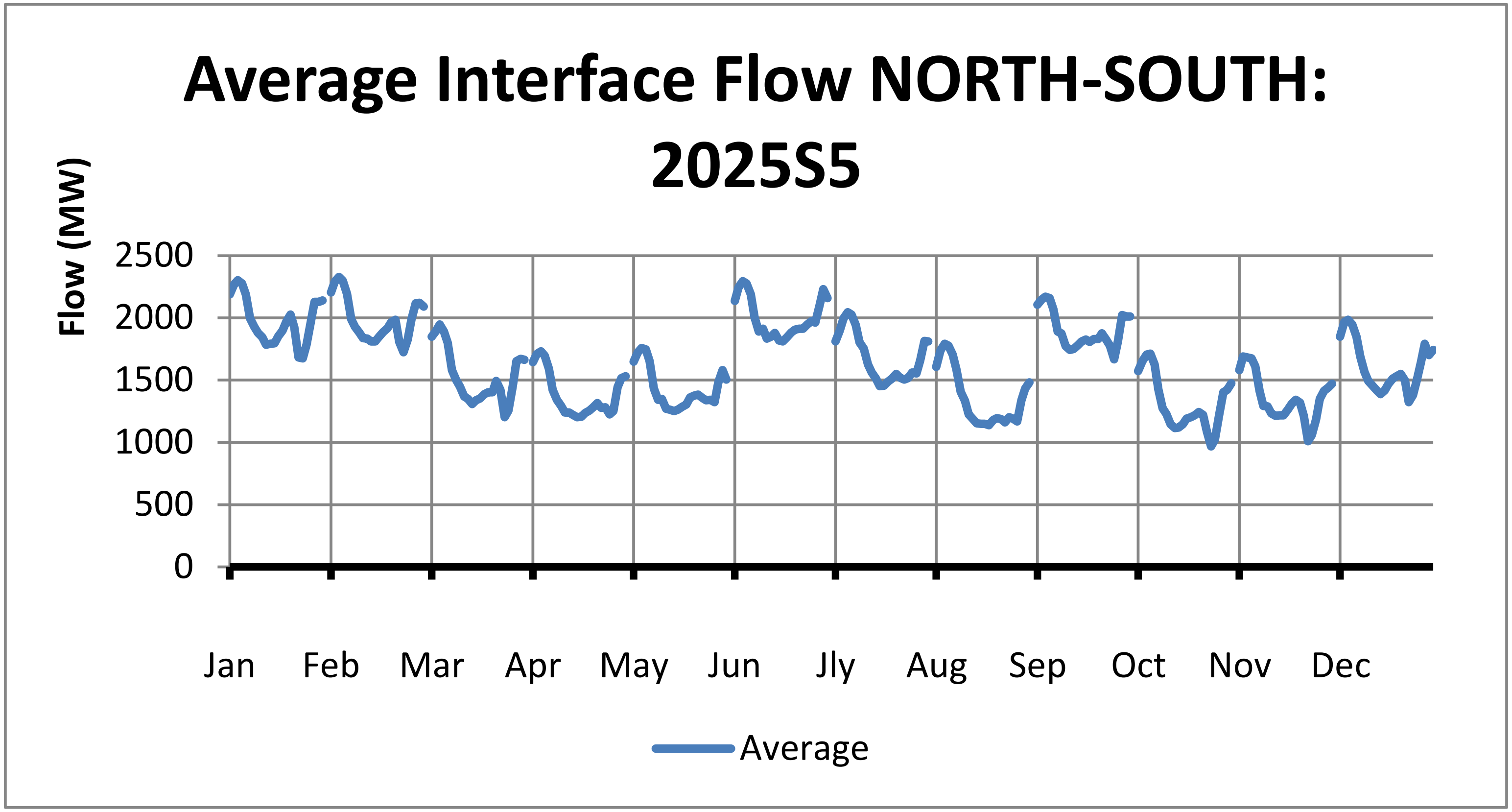
Diurnal Interface Flow: North-South 2025 Constrained Scenario 3



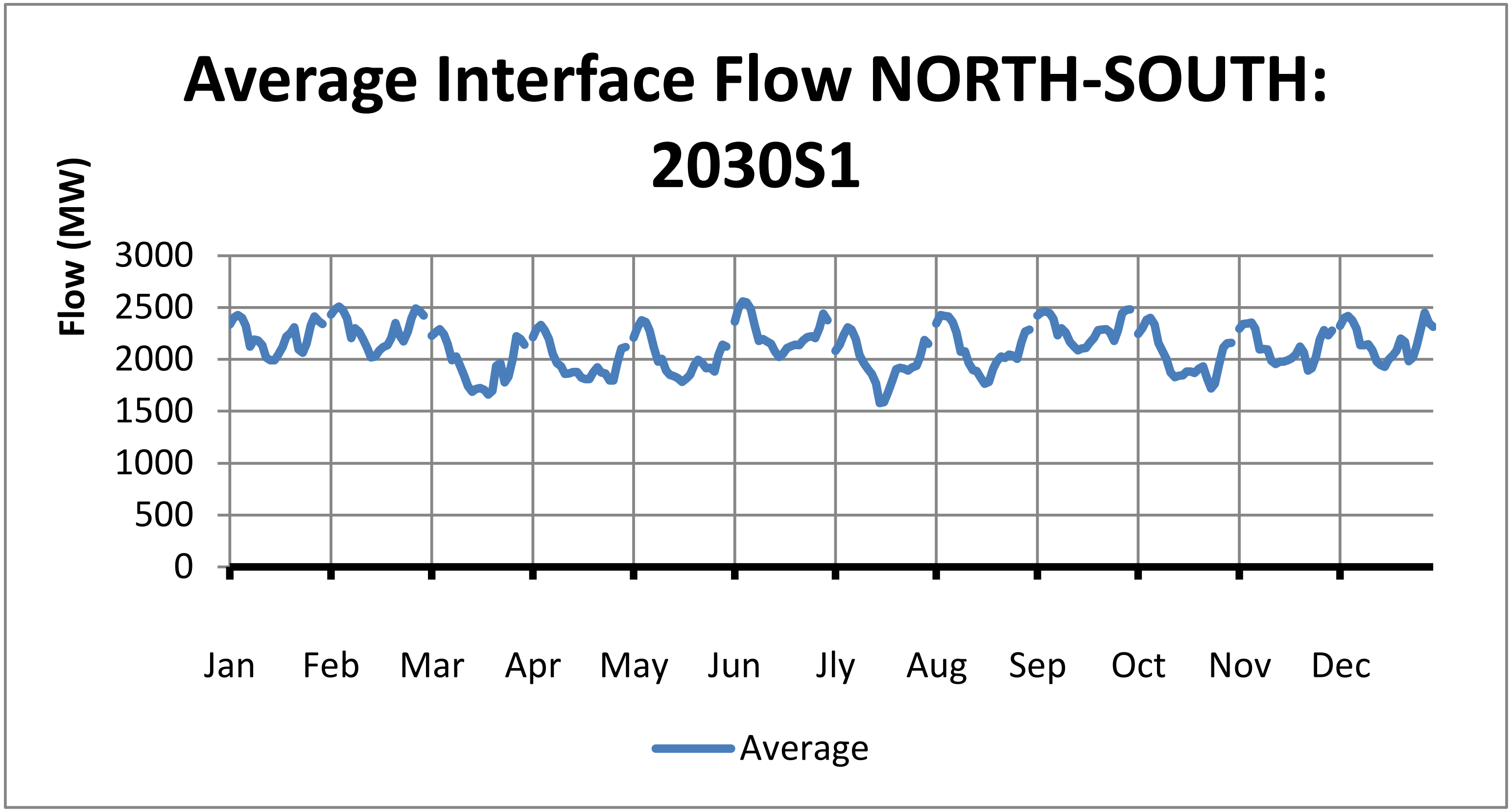
Diurnal Interface Flow: North-South 2025 Constrained Scenario 4



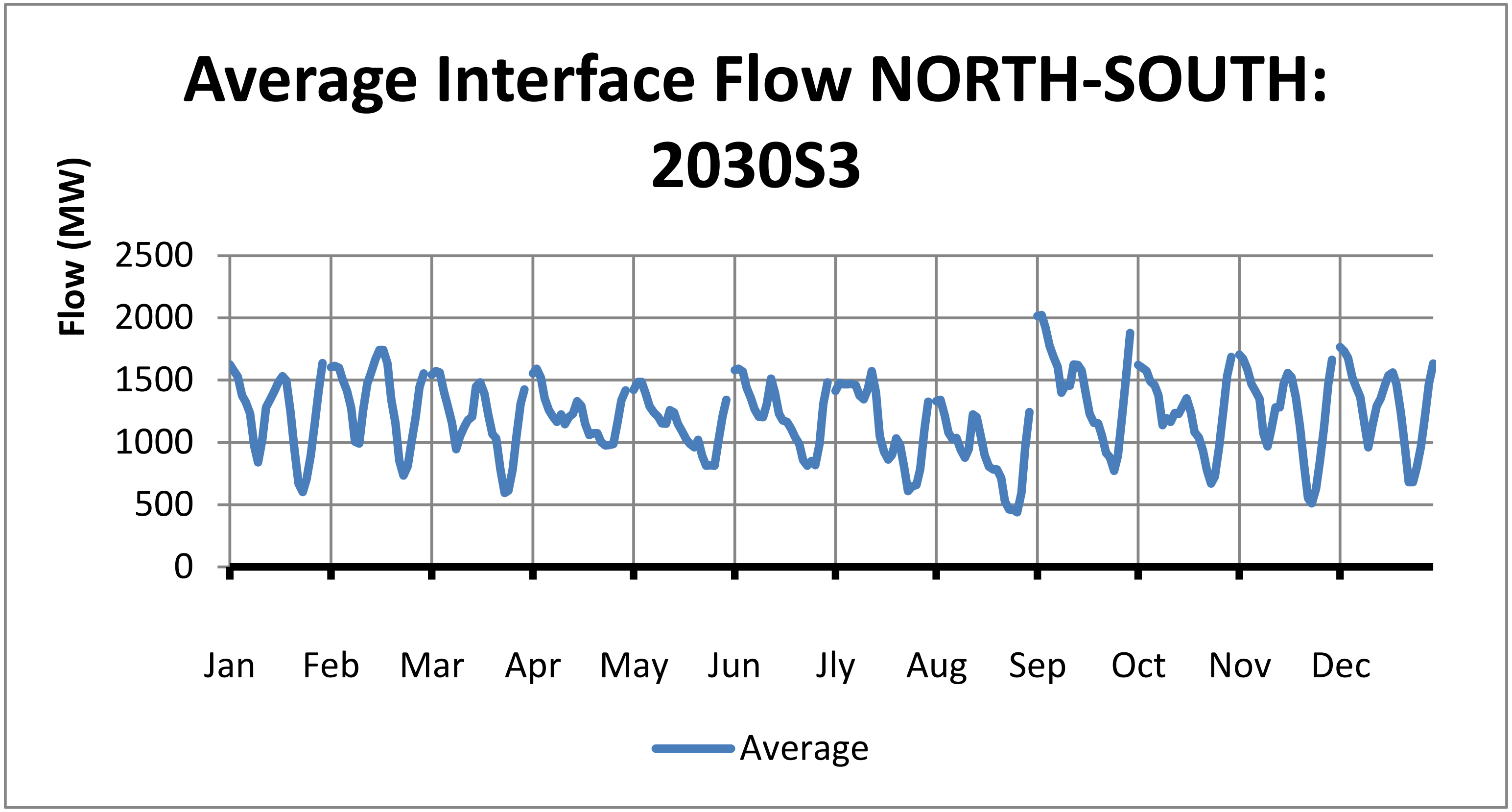
Diurnal Interface Flow: North-South 2025 Constrained Scenario 5



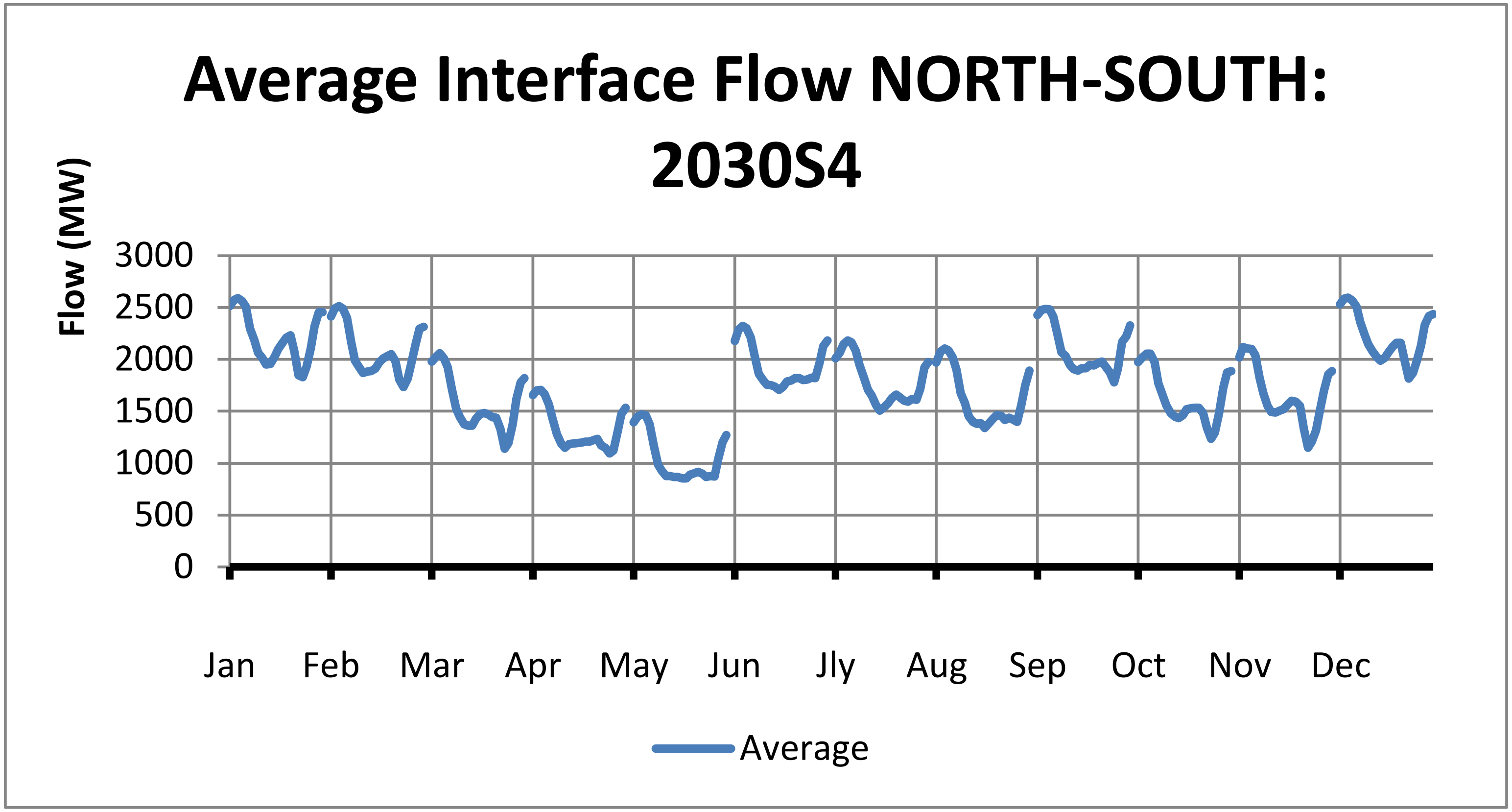
Diurnal Interface Flow: North-South 2030 Constrained Scenario 1



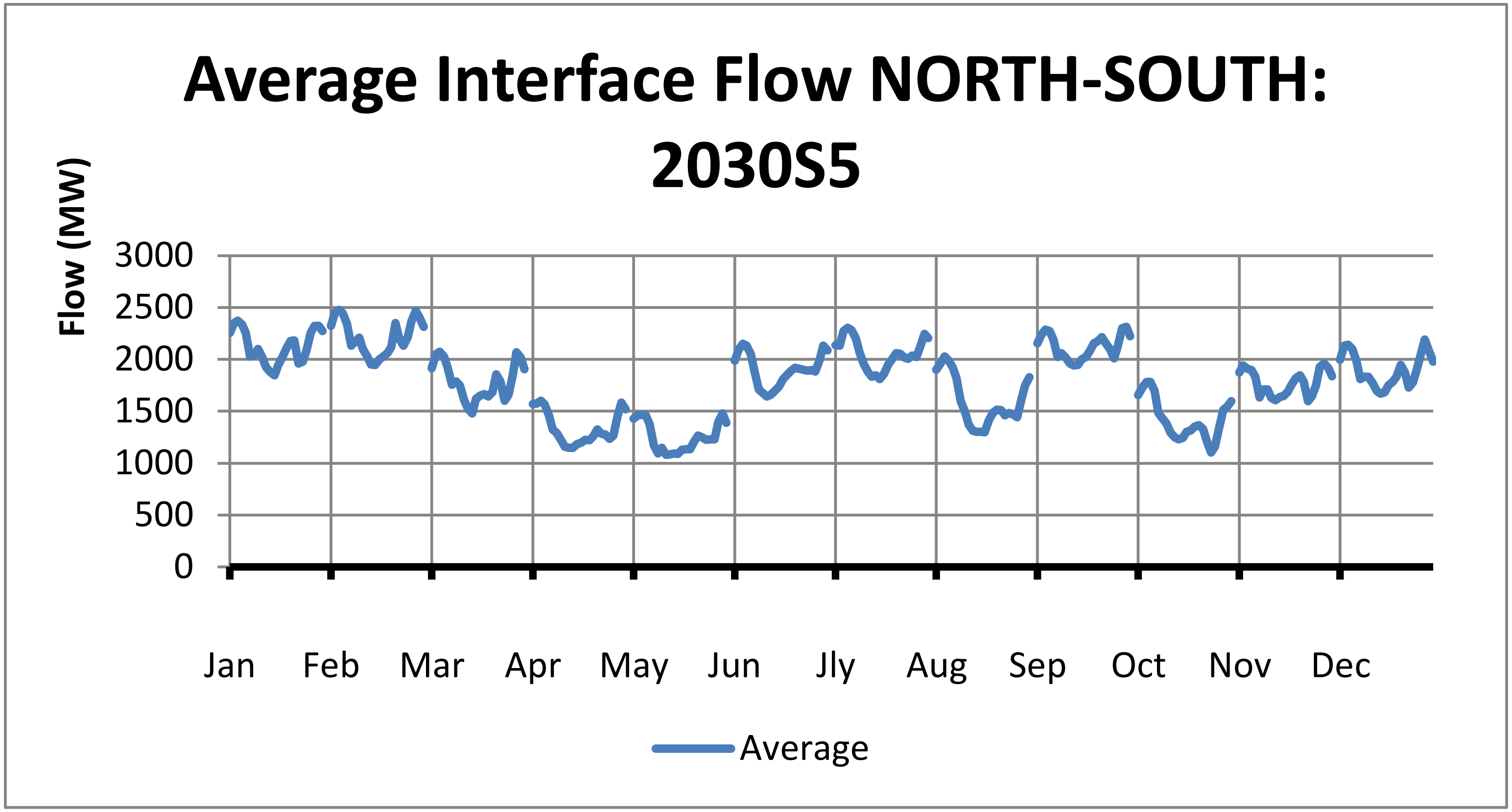
Diurnal Interface Flow: North-South 2030 Constrained Scenario 3



Diurnal Interface Flow: North-South 2030 Constrained Scenario 4



Diurnal Interface Flow: North-South 2030 Constrained Scenario 5

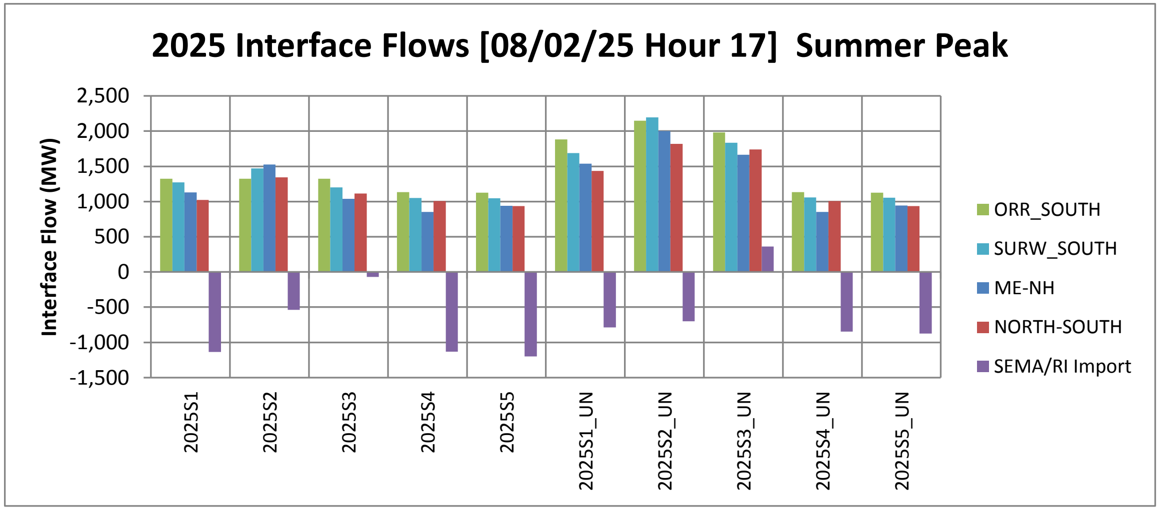


SELECTED HOURS

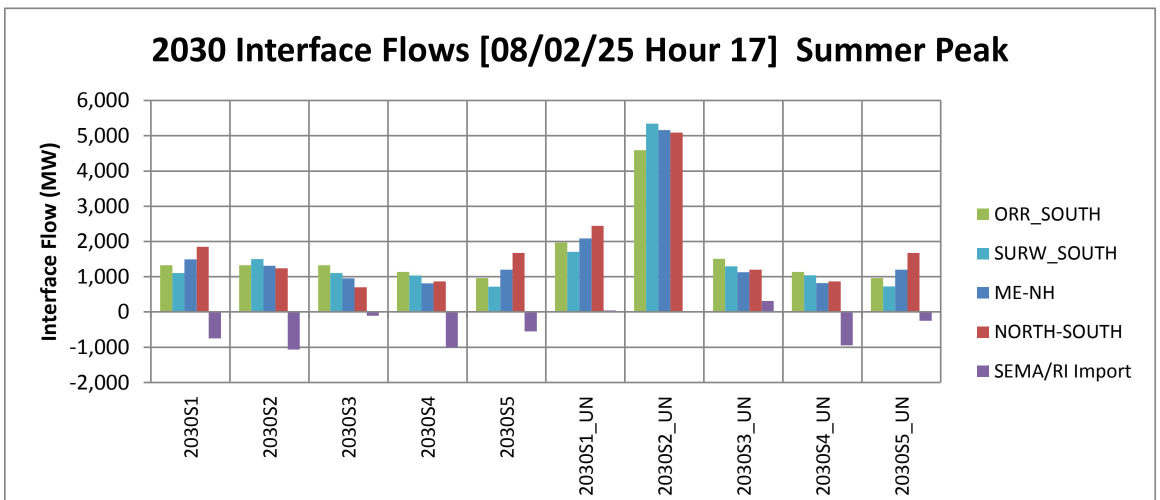
Interface Flows

Interface Flows at Summer Peak Load (Aug 2) All Cases

2025

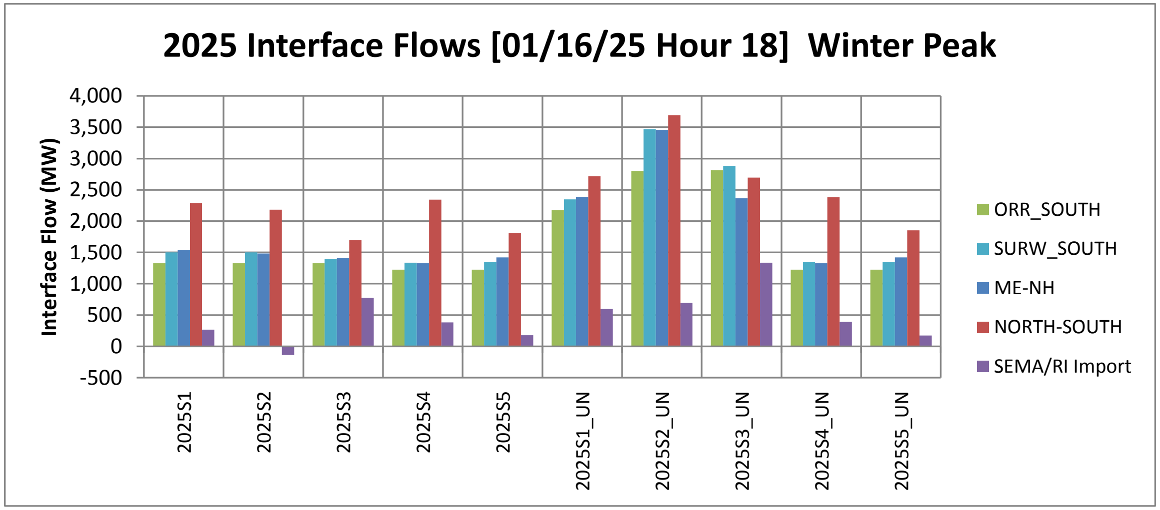


2030

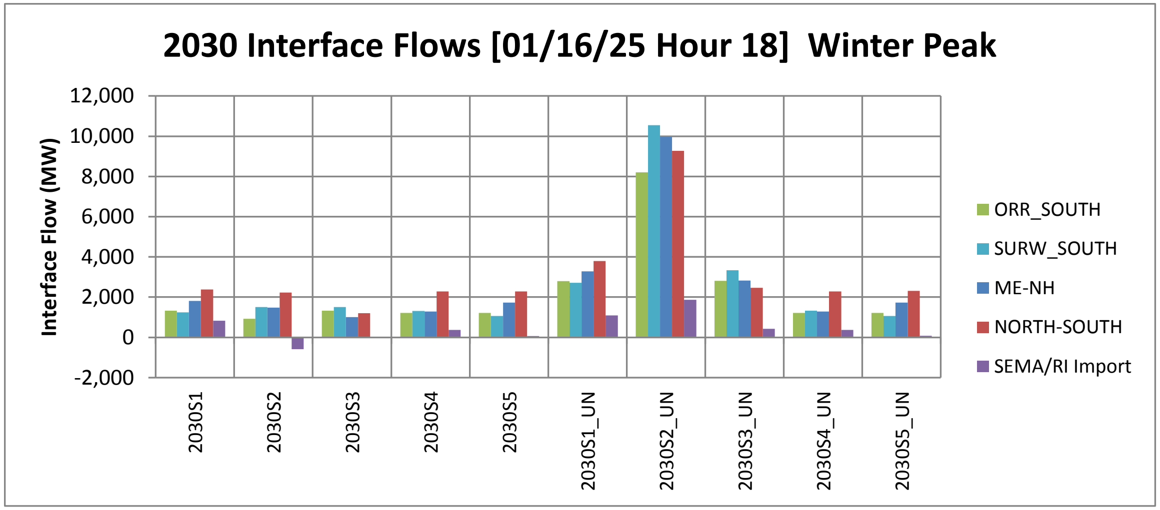


Interface Flows at Winter Peak Load (Jan 16) All Cases

2025

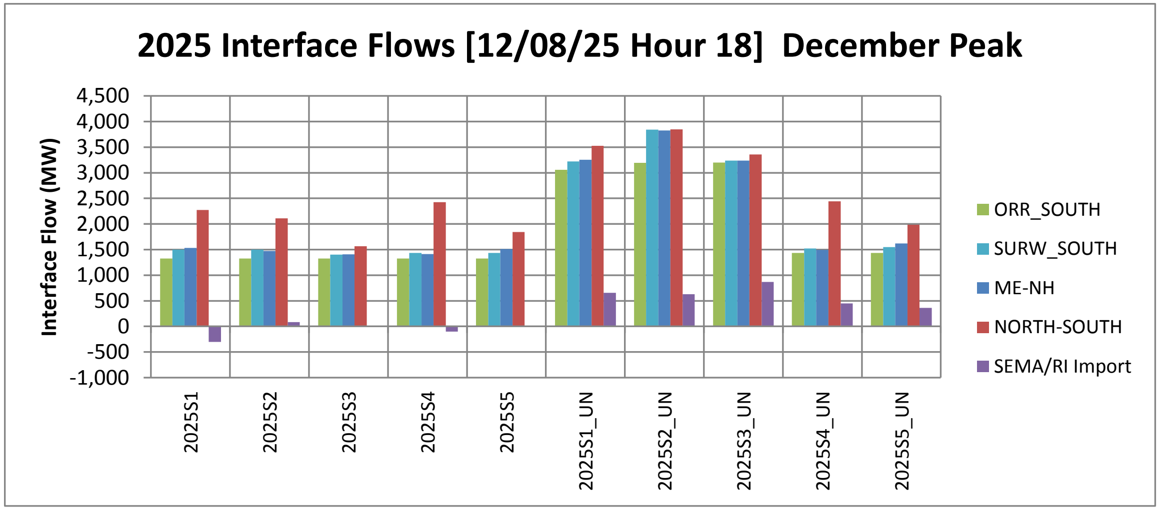


2030

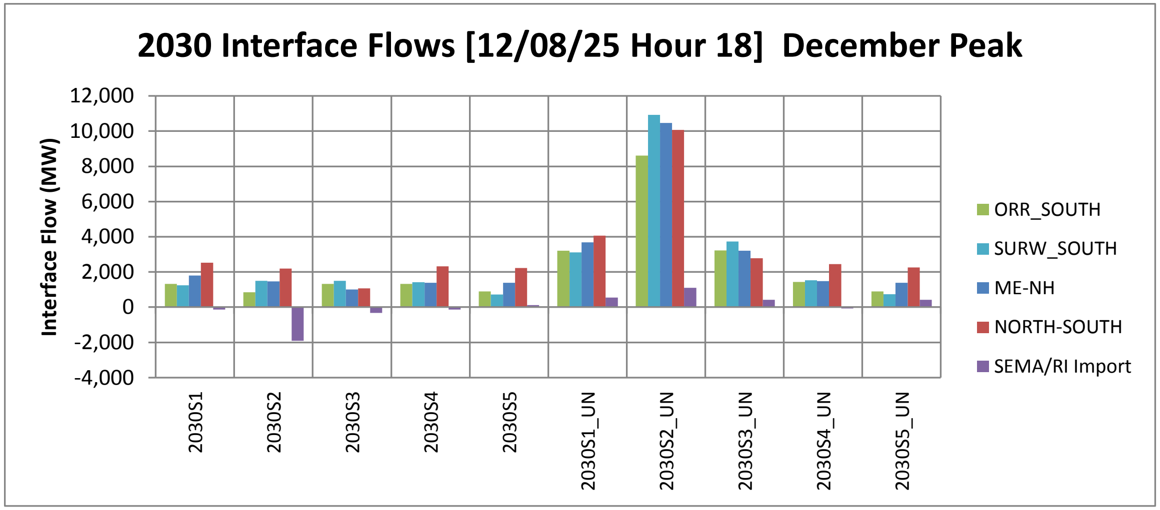


Interface Flows at December Peak Load (Dec 8) All Cases

2025

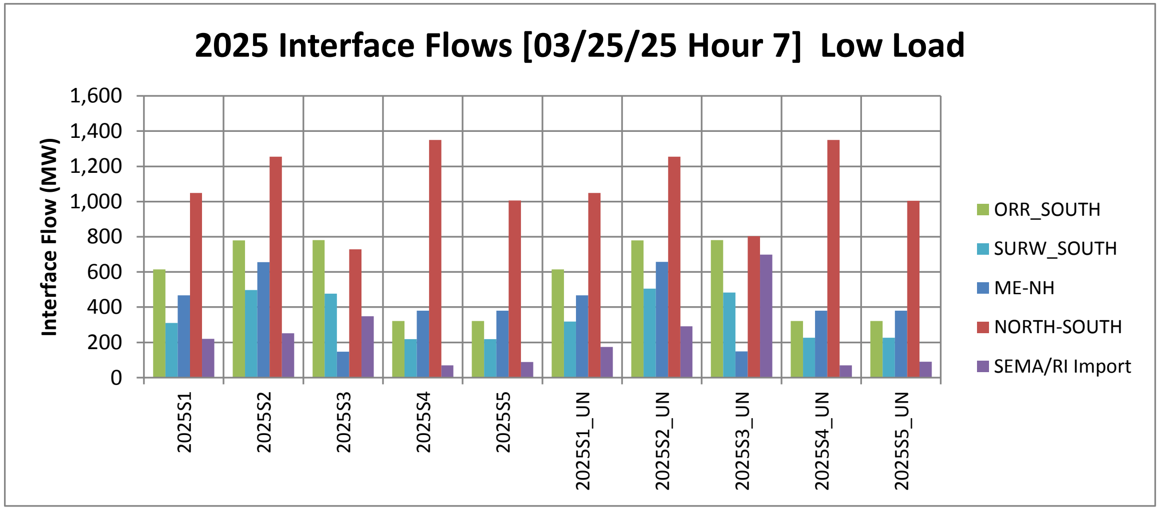


2030



Interface Flows at Low Load Hour (Mar 25) All Cases

2025



2030