Resource Optimization Approach to Tidal Energy

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The Resource

- The energetic potential of ocean tides is manifested as
  - potential energy in resonantly amplified bays or estuaries
  - kinetic energy concentrated in tidal channels
- A substantial world resource (~100 GW capacity) was previously identified at sites with high tidal range, but development has been inhibited by economic and environmental barriers.
- Alternative approaches based on ultra-low-head barrages (“tidal fences”) and free stream current turbines may enable a much larger and more feasible tidal energy resource.
- Canada has excellent sites in the Bay of Fundy, the eastern Arctic and the Pacific coast.

Classification of Tidal Power Strategies

(in order of descending complexity)

- Type A: barrage with gates and pumping mode. Highest working heads.
- Type B: barrage with gates, no pumping. High working heads as a fraction of tidal range.
- Type C: tidal fence (high permeability barrage). No gates. Low working heads.
- Type D: free stream current turbine which may be deployed in “current farm” arrays.

Types A and B: gated barrage

- Turbine working head is a large fraction of the tidal range .
- Mature but mechanically complex technology. Gates needed to open and close barrage.
- Relatively large environmental disturbances.
- Applicable to relatively small basins with large tidal range, unsuitable for sites with deep entrances or strong currents.

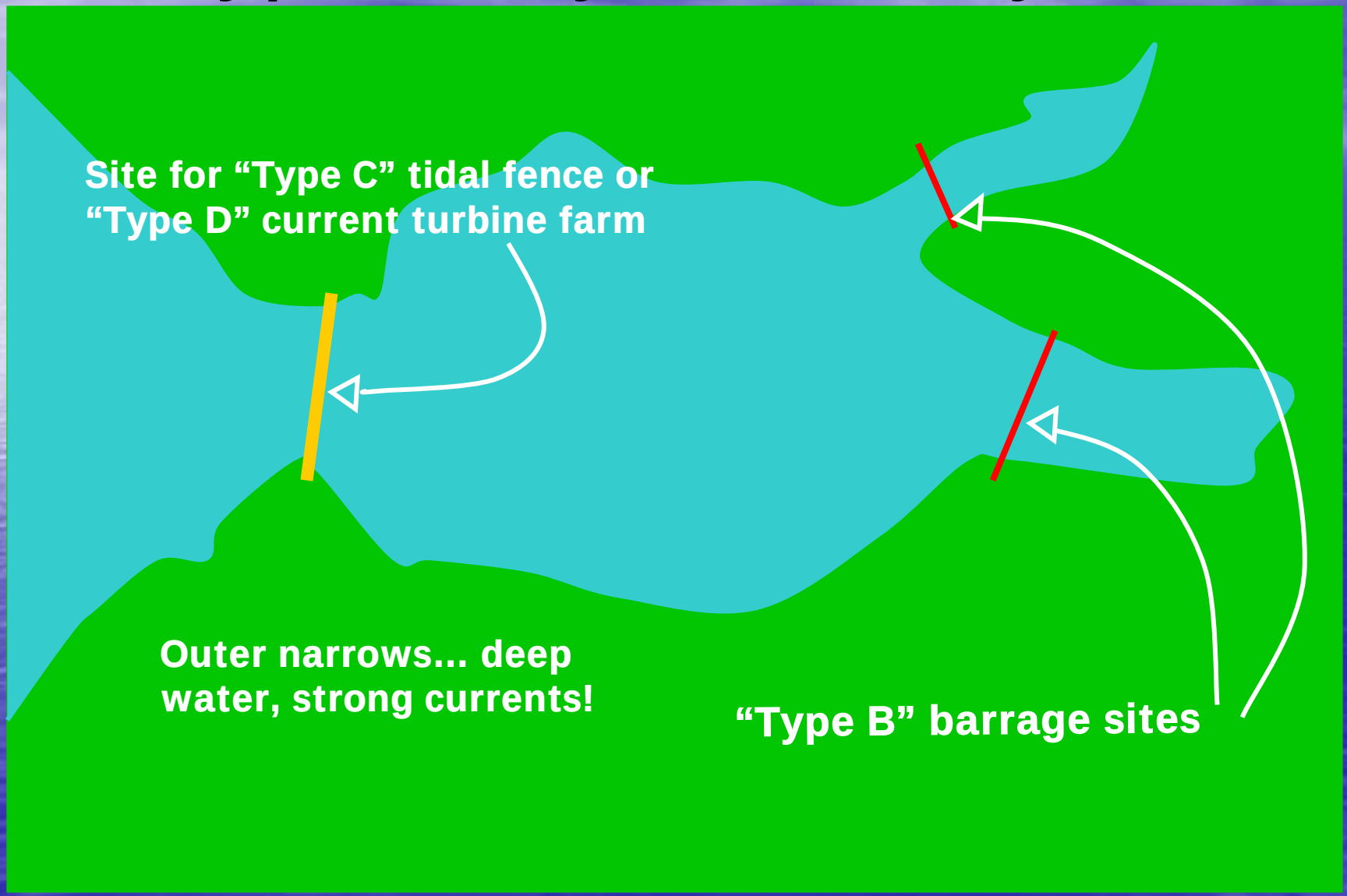
Type C: tidal fence

- Tidal fences are open barrages, intermediate between the gated barrage and free-stream turbines. Propeller or vertical axis turbines are supported between piers of a bridge structure. No gates.
- Can be installed in deeper water or faster currents, and for larger tidal power sites than gated barrages.
- Environmental disturbances less severe than gated barrages, but effects on fisheries and marine mammals must be assessed.
- Civil and mechanical aspects require development and costing.
- Canada has some large potential tidal fence sites, up to 10 GW rating.

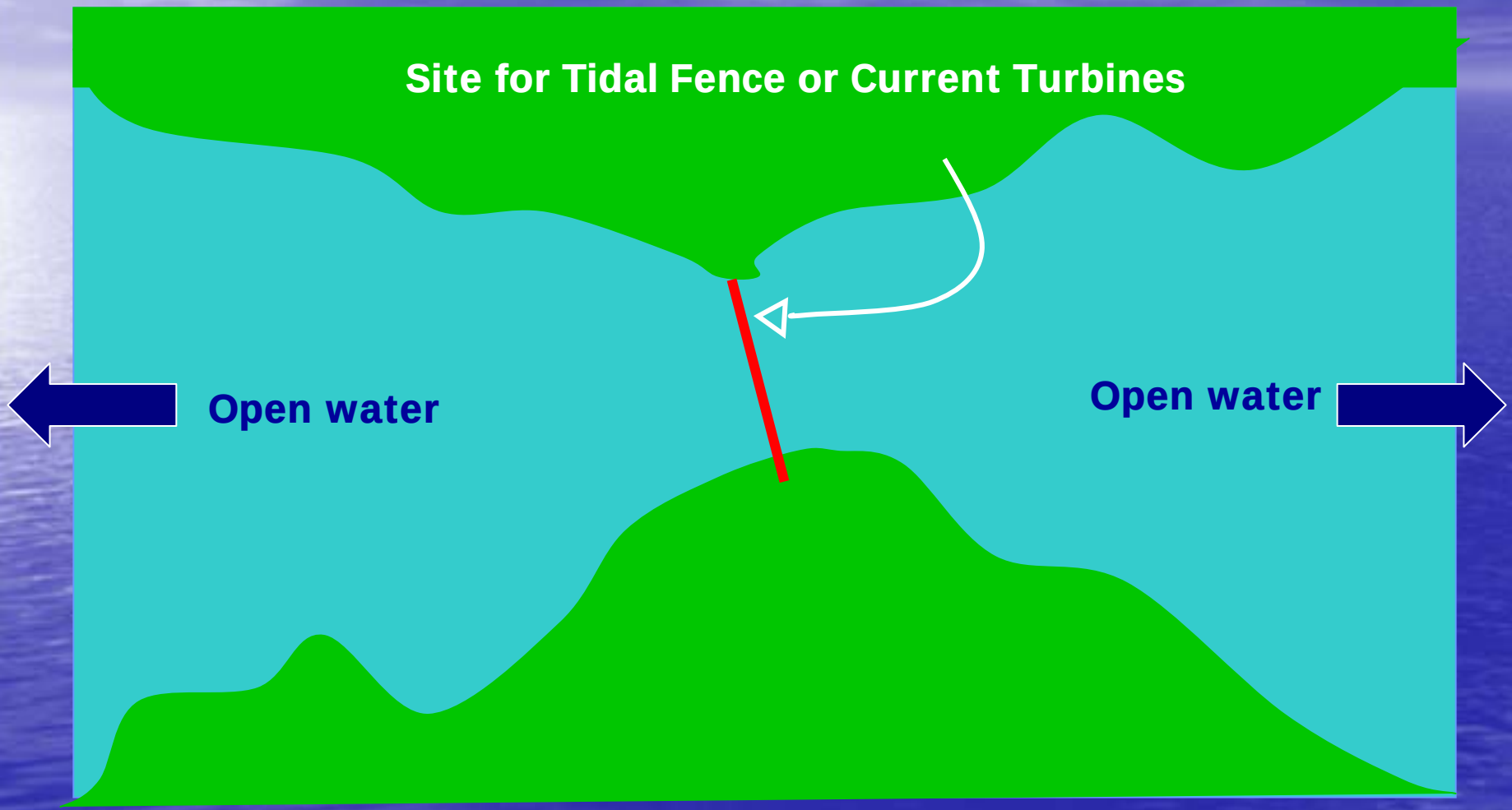
Type D: free-stream current turbines

- Energy captured from kinetic energy of flow. May be deployed as individual turbines or “current turbine farms” of many turbines.
- Advantage of incremental installation, but lower efficiency than tidal fence because of wake separation.
- Environmental impacts would be relatively mild.
- Potentially attractive for sites with strong tidal currents, regardless of vertical amplitudes. Can be deployed in ice-infested waters.
- The B.C. coast has many small potential sites and a few large sites.

Typical bay or estuary site



Tidal Passage (typical B.C. site)



Importance of Types A and C for Resource Inventory Studies

- Type A... pumping mode allows resonance to be approached, thus maximizing idealized energy extraction.
- Type C... tidal fence is the simplest barrage, always open to flow in either direction.
- Type B... gated barrage energy output will be intermediate between Types A and C.
- Type D... current turbine farms are equivalent to a very low head Type C tidal fence in the same channel.

Method for Preliminary Site Modeling

- Select the site to be investigated as a line across a channel or bay. Control variable is flow across this line.
- Ideal power availability is given by product of flow and head difference across the site line. For Types C and D, flow and head difference are in phase.
- Use numerical model for “open channel” (natural flow) and “closed barrage” (zero flow) tidal dynamics, providing linearized impedances for estimating tidal response at any location to varied control flows.
- Use linearized model for preliminary assessment and sensitivity analyses. Use numerical model for rigorous simulation with Type C or D schemes parametrized by an effective discharge coefficient.
- The following examples are from linearized model for a site in Minas Passage (Bay of Fundy). Numerical model showed that tidal fence power output was under-estimated, as expected because of reduced turbulent dissipation with smaller flows in Minas Passage.

Power and Head of Tidal Fence in Minas Passage

Working head across barrage or tidal fence is maximum for phase parameter "alpha"= 0º, the zero flow (closed barrage) limiting case.

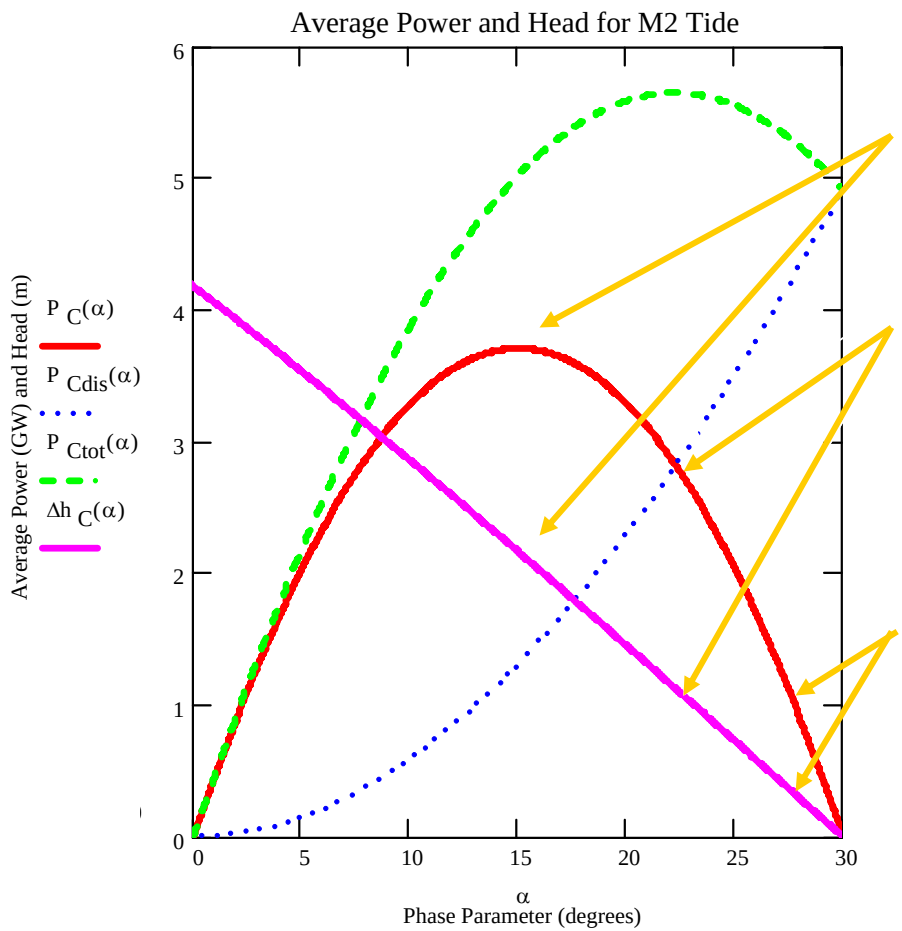
Working head is zero for "alpha" = 30º, the natural flow (open channel) case.

NOTES

P_C is average power available for extraction at 100% efficiency.

P_{Cdis} is tidal power dissipated in channel and basin.

P_{Ctot} is total power extracted and dissipated by tidal fence, channel and basin.



Type C

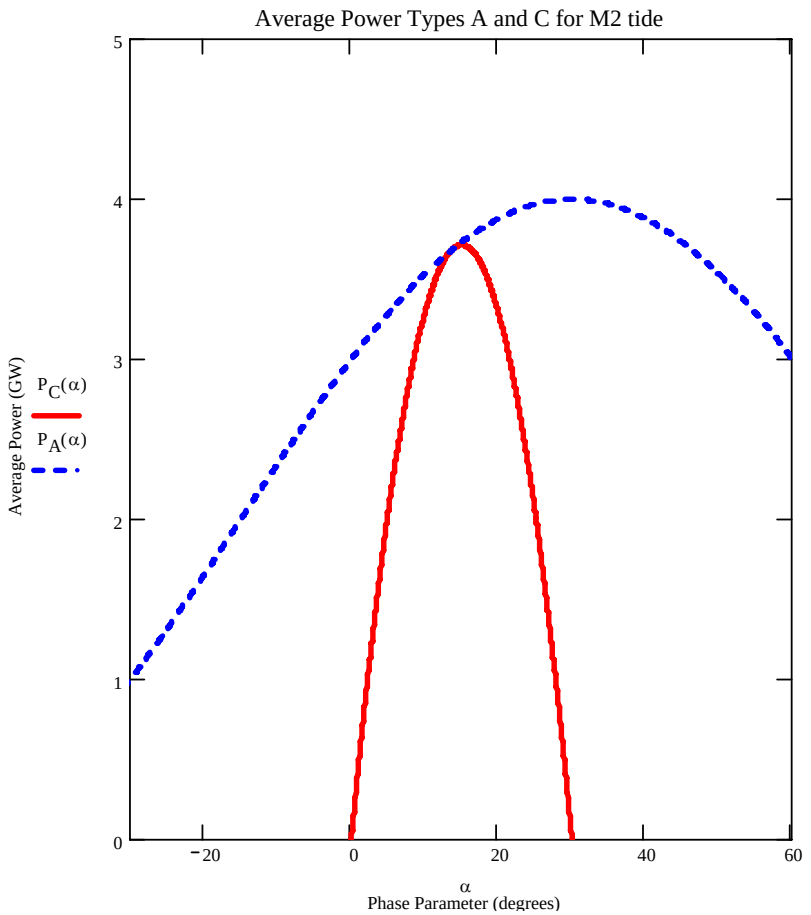
Maximum power tidal fence

Recommended lower head tidal fence

Type D

Current turbine farm

Alternative Control Strategies
Minas Passage tidal power site



P_A and P_C are average power available at 100% efficiency to idealized Type A and C schemes. Type B cannot extract more power than Type A, but may exceed Type C.

Result for Minas Passage Site

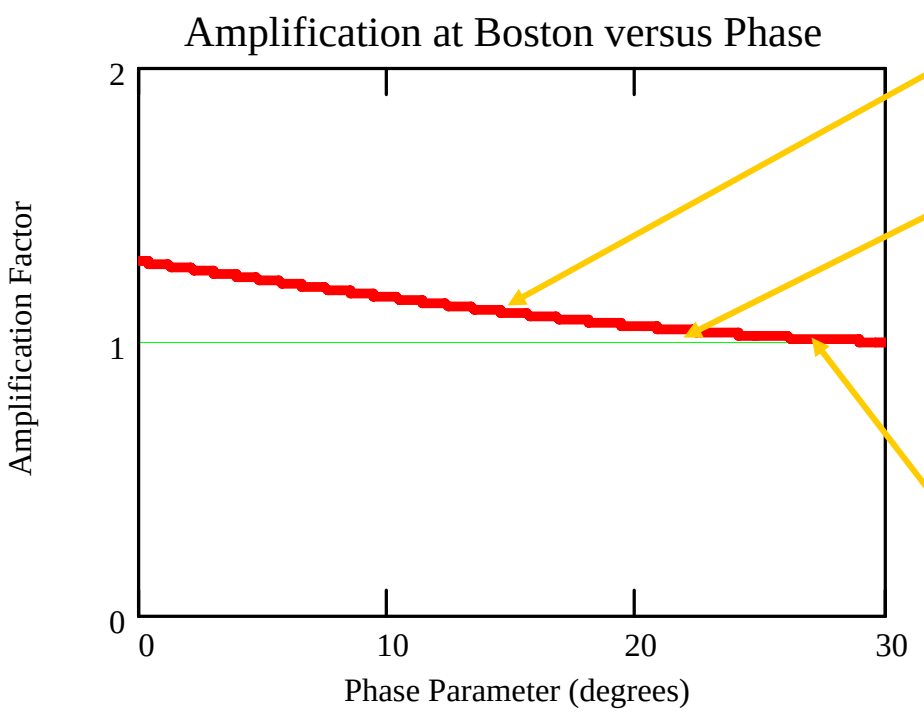
Type A (and therefore Type B) could extract very little more energy than optimized Type C, reflecting near-resonance of the Bay of Fundy system. The relatively simple and low impact Type C "tidal fence" is strongly preferred here.

Far Range Tidal Regime Impacts
(amplification at Boston)

- Previous modeling of a proposed 5 GW Type B barrage in Minas Basin [site B9] showed that there would be an unacceptable 10% amplification of tidal range at Boston.
- The present simplified model indicates that a 5 - 10 GW Type C scheme in Minas Passage could be optimized to reduce such amplification at Boston, by operating at relatively low working heads. This was confirmed using the Greenberg tidal dynamics model.
- Amplification at Boston might be completely eliminated by multiple tidal fence projects in Minas Basin, Chignecto Bay and perhaps Massachusetts Bay.

Reducing Far Range Tidal Regime Impacts

(amplification at Boston from tidal fence in Minas Passage)



Type C

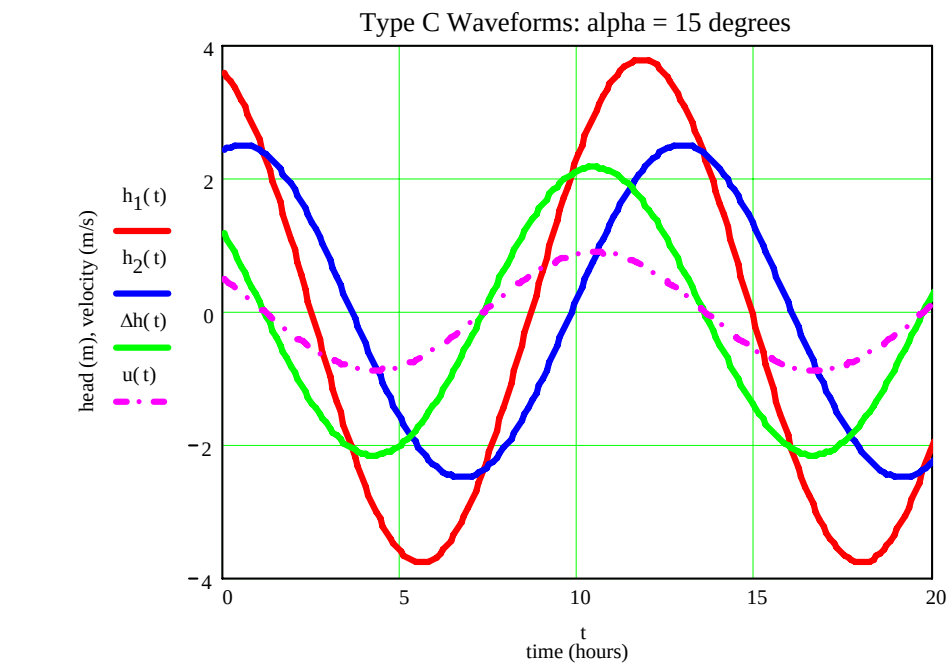
Maximum power tidal fence

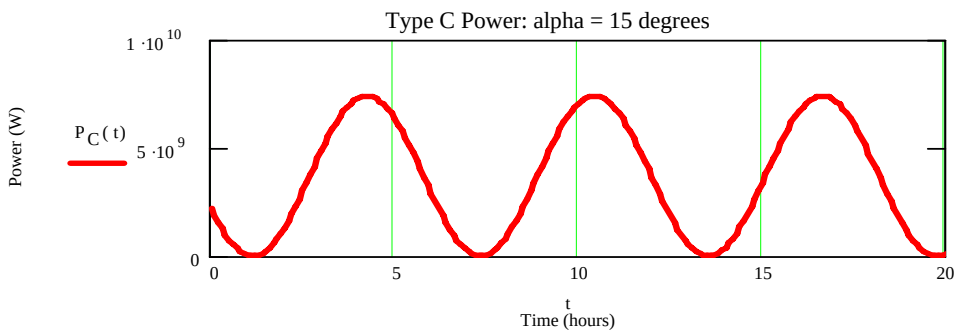
Recommended lower head tidal fence

Type D

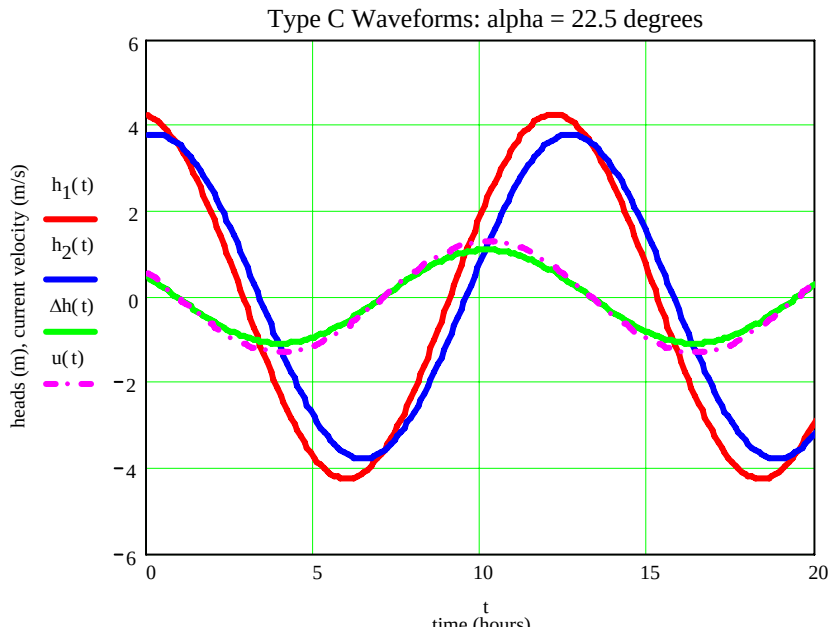
Current turbine farm

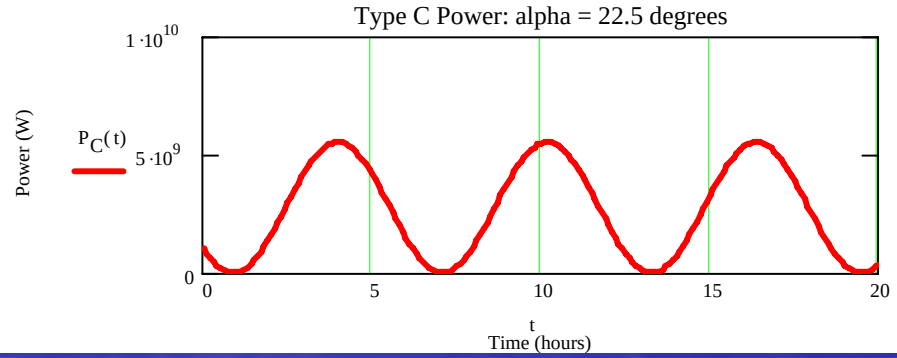
Type C head, flow and power (maximum power)





Type C head, flow and power (lower head)





Power is reduced by ~ 25% compared to maximum power case, but tidal regime disturbances inside basin and outside tidal fence are greatly reduced.

Amplification at Boston is reduced from 10% to 3.4%.

Working head for M2 tide are reduced by a factor of two, to about 1 meter.

What should Canada do?

1. Recognize tidal energy as a major national resource on all three coasts, with high priority for economic and environmental assessment.
2. Modeling studies for control strategy optimization and resource inventory.
3. Economic studies to calibrate tidal energy resource with cost of power from tidal fence and current turbine farm schemes.
4. Pilot installations and demos to validate technology and confirm low impact on marine fauna.

Outlook

- Tidal energy resources of Canada and the world can be greatly expanded by development of current turbine and tidal fence approaches.
- Key challenges include shakedown of engineering alternatives and testing of marine ecology impacts.
- Robust cost correlations and objective evaluation methodology are required.
- Strengthened national and international collaboration will assist inventory and feasibility assessment of tidal energy resources.

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