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NSARB 2023-001

NOVA SCOTIA AQUACULTURE REVIEW BOARD

Applications by KELLY COVE SALMON LTD. for a BOUNDARY AMENDMENT and TWO NEW MARINE FINFISH AQUACULTURE LICENSES and LEASES for the cultivation of ATLANTIC SALMON (Salmo salar) - AQ#1205x, AQ#1432, AQ#1433 in LIVERPOOL BAY, QUEENS COUNTY.

Affidavit of Dr. Edmund Halfyard

I, Dr. Edmund Halfyard, of Middle Sackville, in the Halifax Regional Municipality, Province of Nova Scotia, AFFIRM AS FOLLOWS:

1. I am a research scientist with the Nova Scotia Salmon Association ("**NSSA**"), where I have been employed in some capacity since 2005 and have led full-time science-based conservation programs since April 2016. Among other things, I am responsible for planning and conducting research on Atlantic Salmon and Brook Trout in watersheds from northern Cape Breton to Yarmouth County, including the Medway River watershed.

2. I will be leaving the NSSA at the end of January 2024 to work full-time as the Chief Technology Officer at my climate-tech start-up, CarbonRun Carbon Dioxide Removal Limited. Our mission is to restore the health of rivers and their natural ability to deliver carbon from land to ocean for long-term sequestration.

3. My qualifications as a subject matter expert on the survival, conservation and recovery of wild Atlantic salmon are set out in my Curriculum Vitae, attached to my affidavit as **Exhibit "A".** Among other things, I wrote my PhD thesis on the estuarine and coastal survival of Atlantic salmon and worked for several years with the federal Department of Fisheries and Oceans studying wild salmon populations in Nova Scotia.

4. I am the primary author of the draft report on the Medway River watershed attached to my affidavit as **Exhibit "B"** (the "**Report**"**).** I also designed the data-gathering methodology and supervised the data-gathering process. To gather data, I worked in conjunction with trained and experienced NSSA staff, as well as qualified and trained project partners and collaborators including local river groups like the Medway River Salmon Association and research organizations like Acadia University, Dalhousie University and the Nova Scotia Community College.

5. The Report is only one chapter of a much larger NSSA project aimed at supporting aquatic habitat restoration across Nova Scotia, called the Watershed Assessment Towards Ecosystem Recovery ("**WATER**") project. The WATER project combines local knowledge, publicly available data sources, and cutting-edge monitoring tools to generate new data describing the freshwater habitat of eight watersheds in Nova Scotia identified by NSSA as high priority – the Annapolis River, Medway River, LaHave River, Petite Rivière, Musquodoboit River, West River Sheet Harbour, Moser River, and St. Mary's River watersheds. It is a large-scale project involving four years (2019-2023) of data gathering, funded by the federal Department of Fisheries and Oceans' Canada Nature Fund for Aquatic Species at Risk.

6. The final product of the WATER project will be a report identifying the highest quality habitats within these eight priority watersheds, as well as the habitats most in need of restoration and those offering the most significant benefit to wild Atlantic salmon and other species-at-risk.

7. The Report attached herein details the data collection, results, and analysis applicable to the Medway River watershed only. Although the Report is currently in draft, the data and analysis currently contained in the Report are final. The text reflected in the Report will not change except for basic editing for clarity and typographical errors. In addition, content will be added to the end of the Report under headings 10.3, 10.4 and 10.5.

8. In my expert opinion, the data contained in the Report show that the Medway River watershed contains an abundance of habitat that is suitable for spawning, rearing, and generally supporting populations of wild Atlantic salmon. Atlantic salmon are present in the Medway River, albeit at low numbers. The River has suffered impacts that have decreased its ability to support a large salmon population; however, nearly all of the habitat degradation is reversible and can be addressed through known and attainable restoration methods. In short, the Medway River can be restored to support a large population of wild Atlantic salmon once again, as it did historically.

9. In my opinion, chronic freshwater acidification caused by acid rain is the most pressing restoration need and can be addressed by acid rain mitigation techniques like liming that have been tested and refined within Nova Scotia by the NSSA. In 2001, the NSSA contracted a Norwegian scientist to develop river-specific acid rain mitigation plans for Nova Scotia, and in 2010 the Medway River Salmon Association developed a liming business plan with support from the NSSA. The NSSA now intends to use the findings in the Report to improve upon earlier planning and to support implementation of large-scale acid rain mitigation on the Medway River.

10. I have exercised my professional judgement to the best of my training, knowledge and ability regarding the data, analysis and conclusions set out in the attached Report, and the Report accurately represents my objective opinion on the matters set out therein. The

Report includes all data that is relevant to my expert opinion and highlights any information that could reasonably lead to a different conclusion. I am prepared testify before the Aquaculture Review Board, comply with the Board's directions, and apply independent judgment when assisting the Board.

11. I affirm this affidavit in support of Protect Liverpool Bay Association's intervention before the Aquaculture Review Board and for no other or improper purpose.

Affirmed before me on this 19th day of January, 2024 at Halifax, Nova Scotia	)	
[redacted]	)	[redacted]
A Commissioner of Oaths in and for the Province of Nova Scotia	)	Dr. Edmund Halfyard

Sarah McDonald
Barrister, Solicitor, Notary Public
and a Commissioner of Oaths
in and for the Province of Nova Scotia

This is **Exhibit "A"** referred to in the affidavit of **Dr. Edmund Halfyard,** affirmed before me this 19th day of January, 2024.

[redacted]

Sarah McDonald
A commissioner of the
Supreme Court of Nova Scotia

Sarah McDonald
Barrister, Solicitor, Notary Public
and a Commissioner of Oaths
in and for the Province of Nova Scotia

EDMUND A. HALFYARD

BSc. (Envs), MSc. (Biol), PhD (Biol)
[redacted], NS, [redacted]
[redacted] [redacted]

FORMAL EDUCATION & TRAINING

University of Windsor, Windsor, ON **June 2014 – April 2016**
Post-Doctoral Research Fellow, Great Lake Institute for Environmental Research
Topic: Development and optimization of a novel acoustic telemetry transmitter designed to detection predation events. Additional projects: evaluation of an international reintroduction program for extirpated Deepwater Cisco in Lake Ontario, examination of the interplay between spatial distribution of fish species in the Detroit River as influence by trophic position, habitat quality, localized food-web productivity and seasonal effects. Prof. Dr. Aaron Fisk.

Dalhousie University, Halifax, NS **Class of 2014**
PhD (Fish Biology/Ecology)
Thesis: The estuarine and coastal survival of Atlantic Salmon: estimation, correlates and ecological significance. Profs. Dr. Frederick Whoriskey, Dr. Daniel Ruzzante

Acadia University, Wolfville, NS **Class of 2008**
MSc (Fisheries Biology / Limnology), GPA 3.93 out of 4.0
Thesis: Initial results of an Atlantic Salmon river acid mitigation program
Profs. Dr. Mike Brylinsky, Dr. John Roff

Acadia University, Wolfville, NS **Class of 2003**
BSc. (Environmental Science)

APPOINTMENTS AND PROFESSIONAL EXPERIENCE

Adjunct Professor, University of Windsor **2021 – Present**
Biology Department

Adjunct Professor, Acadia University **2019 – Present**
Biology Department

Honorary Research Associate, University of New Brunswick **2019 – Present**
School of Graduate Studies

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CarbonRun Carbon Dioxide Removal Limited **April 2022 - Present**
Co-Founder, Chief Technology Officer

- Co-conceived principle technological idea. US Provisional Patent.
- Alongside two co-founders, we created all aspects of business development, mission-vision-values, staffing, partnerships and collaborations, regulatory review and compliance, technological innovation and broadly all that is required for a climate-tech start-up.

Nova Scotia Salmon Association, Bedford, NS **April 2016 – January 2024**
Research Scientist & Project Manager: West River Acid Mitigation Project

- Responsible for conceptualization, design, funding, and application of applied research on Atlantic Salmon and Brook Trout.

- Oversight and management of the West River, Sheet Harbour Acid Mitigation Project: a multi-disciplinary restoration initiative with annual budget now exceeding $1.5M.
- Staffing and direct supervision of a team of 11 FTE.
- Co-supervision of several graduate student-led research projects.

Perennia Research, Bible Hill, NS **April 2016 – October 2022**
Research Scientist & Project Manager
- Leading a collaborate team to develop watershed-based stewardship plans for aquatic species at risk in Nova Scotia.
- Development and delivery of applied conservation programs in support of species-at-risk recovery.
- Cross-appointment with position above.

Fisheries and Oceans Canada, Dartmouth, NS **Jan. 2014 – May 2014**
Biologist, Population Ecology Division
- Developed an analytic method to parse migration movements of fish using acoustic telemetry data to assess the role of predation by Striped Bass on endangered Inner Bay of Fundy Atlantic Salmon. Produced a primary publication.

Fisheries and Oceans Canada, Dartmouth, NS **Jan. 2013 – April 2013**
Biologist, Population Ecology Division
- Analyzed data for a recovery potential assessment for Atlantic Salmon of the eastern Cape Breton designatable unit. Produced a research document.
- Developed an analytical approach to estimating seasonal (i.e., summer vs. winter) survival for an endangered Striped Bass population using acoustic telemetry and Cormack-Jolly-Seber Models. Produced a Manuscript.

Fisheries and Oceans Canada, Dartmouth, NS **Jan. 2012 – April 2012**
Biologist, Population Ecology Division
- Analyzed acoustic telemetry on endangered Inner Bay of Fundy Atlantic Salmon
- Provided data management and quality control of an acoustic telemetry metadata and database for multiple tagging projects in the Shubenacadie River Watershed.
- Analyzed acoustic telemetry data on Striped Bass displaying a unique mixed lacustrine and anadromous life history.

Fisheries and Oceans Canada, Dartmouth, NS **Jan. 2010 – May 2010**
Fisheries Technician, Population Ecology Division
- Conducted field research at the Morgan's Falls field monitoring station.
- Planning for installation of a rotary screw trap (smolt wheel) on the St. Mary's River.

Acadia University, Wolfville, NS **Sept. 2009 – Jan. 2010**
Term Instructor, Biology Department
- Sole instructor for Ichthyology 5223, a graduate-level class.
- Responsible for all aspects of lesson planning, exams and marking.
- Supervision and mentoring of teaching assistant.

Salmon Smolt Estimation Project, Sheet Harbour, NS **April 2007 – June 2015**
Lead Researcher
- Funded by the Nova Scotia Salmon Association.
- Installed and operated a rotary screw trap.
- Designed, conducted, and analyzed a stratified mark/recapture for estimation of smolt emigration.
- Implementation of a supportive rearing program – partnership with DFO Maritimes.

Fisheries Consultant, Halifax, NS **June 2007 – Present**
Researcher
- Biological assessments, risk analyses and literature reviews for federal government, provincial government, private industry, and environmental not-for-profit groups.
- Provided science advice to resource managers (e.g., Federal DFO, Gulf Region).

Nova Scotia Department of Fisheries and Aquaculture, Inland Fisheries Division
Pictou, NS **Sept. 2007 – Sept. 2008**
Fisheries Biologist
- Conducted research on Brook Trout and Brown Trout including population assessment, fecundity research and population modelling.
- Researched mercury and arsenic contamination in relation to historic gold mines.
- Assessed early colonization of illegally introduced Smallmouth Bass.

Acid Mitigation Project, Sheet Harbour, NS **April 2005 – Sept. 2009**
Lead Researcher, Nova Scotia Salmon Association
- Designed project monitoring regime
- Conducted fish community research -mark/recapture, electrofishing, netting and angling
- Monitored changes in the aquatic invertebrate communities
- Monitored and analyzed water chemistry, hydrology, periphyton and aufwuchs community
- Surveyed aquatic macrophytes

Acadia Center for Estuarine Research, Wolfville NS **May 2003 – June 2007**
Biological Researcher – Field Assistant
- Muzroll Lake liming project, Doaktown, NB. Installation and maintenance of water chemistry data loggers, insect sampling traps, periphyton traps, core sampling, zooplankton sampling, water chemistry analysis
- Cornwallis River Greencover Riparian Restoration Project, Annapolis Valley, NS. Data logger installation and maintenance
- Windsor mudflats project, Windsor, NS. Data logger installation and maintenance

Acadia University, Wolfville NS **Sept. 2006 – May 2007**
Supervisor
- Immediate supervision of an undergraduate honours student in field and laboratory settings
- Responsible for developing an undergraduate honours project, advertising position, interview process
- Responsible for hiring, training, and supervising two undergraduate technicians working on an aquatic invertebrate monitoring program
- Project design and implementation

FUNDING AND GRANTS

Extensive experience with successful grant writing and administration with > 30 successful grants since 2009. Highlights of grants earned include:

- **Canada Nature Fund for Aquatic Species-at-Risk, Fisheries and Oceans Canada**
  - Term: 2022 – 2026; Cash contribution: **$1,127,675 CAD**; PI
  - Project: *Recovering aquatic species-at-risk through meaningful collaboration, applied conservation planning, and innovative science in Nova Scotia*
  - Partners: Nova Scotia Salmon Association & 13 additional partnering organizations

- **Cluster Funding Agreement, MITACS**
  - Term: 2022 – 2026; Cash contribution: **$245,916 CAD**; Co-PI
  - Project: *Investigating freshwater habitat conditions of Atlantic salmon (Salmo salar) and subsequent effects on growth, condition, and marine survival*
  - Partners: Nova Scotia Salmon Association, Gespe'gewaq Mi'gmaq Resource Council, Atlantic Salmon Research Joint Venture, Institut national de la recherche scientifique (Quebec)

- **Ecosystems and Oceans Science Contribution Framework, Fisheries and Oceans Canada**
  - Term: 2021-2024; Cash contribution: **$595,390 CAD**; Co-PI
  - Project: *Linking freshwater habitat conditions to Atlantic salmon marine survival*
  - Partners: Nova Scotia Salmon Association, Gespe'gewaq Mi'gmaq Resource Council, Atlantic Salmon Research Joint Venture, Institut national de la recherche scientifique (Quebec), University of New Brunswick, NOAA USA, & 8 additional partnering organizations

- **Province of Nova Scotia – Perennia – NS Salmon Association partnership agreement**
  - Term: 2016 – 2023; Cash contribution: **$798,000 CAD**; PI
  - Project: *Support for cross-appointment of Atlantic Salmon Research Scientist*
  - Partners: Nova Scotia Salmon Association, Perennia, NS Department of Fisheries and Aquaculture

- **Canada Nature Fund for Aquatic Species-at-Risk, Fisheries and Oceans Canada**
  - Term: 2019 – 2023; Cash contribution: **$3,086,491 CAD**; PI
  - Project: *An Integrated Approach for the Recovery of Nova Scotia Southern Upland Aquatic Species at Risk*
  - Partners: Nova Scotia Salmon Association, Dalhousie University, Acadia University, Nova Scotia Community College & 9 additional partners

- **Coastal Restoration Fund, Fisheries and Oceans Canada**
  - Term: 2019-2022; Cash contribution: **$663,649 CAD**; PI
  - Project: *Healthy Rivers Promote a Healthy Coastline: Restoring Nova Scotia's Southern Upland Rivers to Promote a Healthier Coastal Ecosystem*
  - Partners: Nova Scotia Salmon Association, Eastern Shore Wildlife Association, Thaumas Environmental Consulting, Province of NS and 6 other partner organizations

- **Ocean and Freshwater Science Contribution Program, Fisheries and Oceans Canada**
  - Term: 2018-2019, Cash contribution: **$44,000 CAD**; Co-PI
  - Project: *Evaluating the potential of open-ocean acoustic telemetry of Atlantic salmon*
  - Partners: Nova Scotia Salmon Association, Ocean Tracking Network, MacQuarrie University, Atlantic Salmon Federation

- **Innovative Communities Fund, Atlantic Canada Opportunities Agency (ACOA)**
  - Term: 2016-2018; Cash contribution: **$381,000 CAD**; PI
  - Project: *Developing a model for the reestablishment of salmon and trout fisheries in Nova Scotia*
  - Partners: Nova Scotia Salmon Association & 9 partnering organizations

- **Recreational Fisheries Partnerships Program, Fisheries and Oceans Canada**
  - Term: 2016-2019; Cash contribution: **$739,108 CAD**; PI
  - Project: *The West River, Sheet Harbour Acid Rain Mitigation and Restoration Project*
  - Partners: Nova Scotia Salmon Association & 9 partnering organizations

- **NSERC Engage PDF Funding**
  - Term: 2014-2016; Cash contribution: **$50,000 CAD**; Co-PI
  - Project: *Development of an acoustic telemetry transmitter for identifying predation event*
  - Partners: University of Windsor, Amirix/Vemco

- **MITACS Accelerate PDF Funding**
  - Term: 2014-2016; Cash contribution: **$45,000 CAD**; Co-PI
  - Project: *Development of an acoustic telemetry transmitter for identifying predation event*
  - Partners: University of Windsor, Amirix/Vemco

- **Atlantic Salmon Conservation Foundation**
  - Term: 2010-2021; Cash contribution: **$190,000 CAD**; PI
  - Project: Monitoring of an acid rain mitigation project and acoustic telemetry of salmon smolts
  - Partners: Nova Scotia Salmon Association, Eastern Shore Wildlife Association, Perennia, Province of Nova Scotia, Dalhousie University, The Ocean Tracking Network

OTHER FISHERIES EXPERIENCE

Atlantic Salmon Research Joint Venture (ASRJV), Moncton, NB **Feb. 2016 – Present**

- Co-chair of science committee *(beginning Oct. 2019)*
- *Co-lead on multi-agency collaborative project examining linkages between freshwater and marine environments in Atlantic Salmon*
- The ASRJV was established to forge the partnerships and collaboration sufficient to address these urgent and unresolved scientific questions that might otherwise not be undertaken
- Formed in 2016. Membership includes Federal, Provincial and State agencies; Indigenous organizations and governments; environmental NGOs; and academia in Canada and the US

Southern Upland Acid Rain Mitigation Committee (SUARMC) **Sept 2005 – Feb. 2019**

- Chair (2016-2019)
- The SUARMC was established in 2004 to guide acid rain mitigation efforts in eastern Canada and provide a platform such that efforts could be coordinated and that groups worked within a strategic framework
- Membership includes Federal and Provincial agencies; Indigenous organizations and governments; non-government organizations; and academia in NS

External reviewer, Atlantic Whitefish Strategic Planning Exercise **Oct. 2017**

- Reviewed plans and contributed to decisions about recovery planning for Atlantic Whitefish, with particular focus on predation, as required under the Canadian Species at Risk Act (SARA)

Southern Upland Atlantic Salmon Recovery Working Group, Halifax, NS Jan. 2013 – June 2018

- Member representing academia and ENGOs
- Provided advice on relevant scientific and conservation issues related to restoring Atlantic Salmon in the Southern Upland, with specific focus on the issues of marine ecology, acidification, and invasive aquatic species

Aquatic Invasive Fish Working Group, Halifax, NS **Jan. 2011 – 2016**

- Co-founder and member of provincial 6-chair group. Membership comprised of all major fisheries organizations operating in NS
- Provided external advice to the province of Nova Scotia on issues of non-native and invasive aquatic species

Reviewer, Recovery Potential Assessment for Striped Bass, Bay of Fundy DU **Feb. 2014**

- Reviewed documentations and contributed to informed decisions about recovery planning as required under the Canadian Species at Risk Act

Inland Fisheries Advisory Council, Halifax, NS **Jan. 2006 – Nov. 2014**

- Member of provincial minister-appointed 8-chair council. Membership comprised of all major fisheries organizations operating in Nova Scotia
- Provide external advice to Nova Scotia Department of Fisheries and Aquaculture regarding all aspect of the freshwater fisheries in NS

Sportfish Habitat Fund Board **Jan. 2006 – Nov. 2014**

- Member of provincial minister-appointed 6-chair board
- Review proposals and grant funds to not-for-profit organizations for habitat and/or access to fisheries projects

PRIMARY PUBLICATIONS

16. Semeniuk, C.A.D., Jeffries, K.M., Li, T., Bettles, C.M., Cooke, S.J., Dufour, B., **Halfyard, E**., Heath, J.W., Keeshig, K., Mandrak, N., Muir, A., Postma, L. & Heath, D.D. (2022). Innovating transcriptomics for practitioners in freshwater fish management and conservation: best practices across diverse resource-sector users. Reviews in Fish Biology and Fisheries, 1-19.

15. Sterling, S. M., Clair, T. A., **Halfyard, E.A**., Keys, K., Rotteveel, L. and O'Driscoll, N. (2022). Kejimkujik Calibrated Catchments: a benchmark dataset for long-term impacts of terrestrial acidification. Hydrological Processes, 36(2), e14477.

14. Lennox RJ, Alexandre CM, Almeida PR, Bailey KM, Barlaup BT, Bøe K, Breukelaar A, Erkinaro J, Forseth T, Gabrielsen S-E, **Halfyard E**, Hanssen EM, Karlsson S, Koch S, Koed A, Langåker RM, Lo H, Lucas MC, Mahlum S, Perrier C, Pulg U, Sheehan T, Skoglund H, Svenning M, Thorstad EB, Velle G, Whoriskey FG, & Vollset KW. (*In Press*). The quest for successful Atlantic salmon restoration- perspectives, priorities, and maxims. 2021. *ICES Journal of Marine Science,* Volume 78, Issue 10, December 2021, Pages 3479–3497. https://doi.org/10.1093/icesjms/fsab201

13. Kuai, Y., Klinard, N. V., Fisk, A. T., Johnson, T. B., **Halfyard, E. A.,** Webber, D. M., Smedbol, S.J, & Wells, M. G. (2021). Strong thermal stratification reduces detection efficiency and range of acoustic telemetry in a large freshwater lake. Animal Biotelemetry, 9(1), 1-13.

12. Sterling, S. M., MacLeod, S., Rotteveel, L., Hart, K., Clair, T. A., **Halfyard, E. A**., & O'Brien, N. L. (2020). Ionic aluminium concentrations exceed thresholds for aquatic health in Nova Scotian rivers, even during conditions of high dissolved organic carbon and low flow. Hydrology and Earth System Sciences, 24(10), 4763-4775.

11. Klinard, Natalie V., Jordan K. Matley, **Edmund A. Halfyard**, Michael Connerton, Timothy B. Johnson, and Aaron T. Fisk. (2020). Post-stocking dispersion, habitat use, and fate of a reintroduced deepwater forage fish in a large lake. Freshwater Biology 65:1073-1085. https://doi.org/10.1111/fwb.13491

10. Klinard, Natalie V., **Edmund A. Halfyard**, Jordan K. Matley, Aaron T. Fisk and Timothy B. Johnson. (2019). The influence of array design and environmental factors on detection efficiency of acoustic transmitters in a large, deep, freshwater lake. Anim Biotelemetry 7: 17. https://doi.org/10.1186/s40317-019-0179-1

9. Klinard, N. V., **Halfyard, E. A**., Fisk, A. T., Stewart, T. J., and Johnson, T. B. (2018). Effects of Surgically Implanted Acoustic Tags on Body Condition, Growth, and Survival in a Small Laterally Compressed Forage Fish. Trans. Am. Fish. Soc. 147(4):749-757. https://doi.org/10.1002/tafs.10064

8. Klinard, N. V., Fisk, A. T., Kessel, S. T., **Halfyard, E. A.,** and Colborne, S. F. (2017). Habitat use and small-scale residence patterns of sympatric sunfish species in a large temperate river. Can. J. Fish. Aquat. Sci. (999), 1-11. https://doi.org/10.1139/cjfas-2017-0125

7. Halfyard, Edmund A., D. Webber, J. del Papa, T. Leadley, S.T. Kessel, S.F. Colborne and A.T. Fisk. (2017). Evaluation of an acoustic telemetry transmitter designed to identify predation events. Meth. Ecol. Evol. https://doi.org/10.1111/2041-210X.12726

6. Cook, K.V., Hinch, S.G., Drenner, S.M., **Halfyard, E.A**., Raby, G.D., and Cooke, S.J. (2017). Population-specific mortality in coho salmon (*Oncorhynchus kisutch*) released from a purse seine fishery. ICES. J. Mar. Sci. 75(1): 309-318. https://doi.org/10.1093/icesjms/fsx129

5. Mumby, J.A., T.B. Johnson, T.J. Stewart, **E.A. Halfyard**, B.C. Weidel, M.G. Walsh, J.R. Lantry and A.T. Fisk. (2017). Feeding ecology and niche overlap of Lake Ontario offshore forage fish assessed with stable isotopes. 75(5): 759-771. Can. J. Fish. Aquat. Sci. https://doi.org/10.1139/cjfas-2016-0150

4. Gibson, A.J.F**., Halfyard, E.A**., Bradford, R.G., Stokesbury, M. and A. Redden. (2015). Effects of predation on telemetry-based survival estimates: insights from a study on endangered Atlantic salmon smolts. Can. J. Fish. Aquat. Sci. 72(5): 728-741. https://doi.org/10.1139/cjfas-2014-0245

3. Halfyard, E.A., Gibson, A.J.F., Stokesbury, M.J.W., Ruzzante, D.E. and Whoriskey, F.G. (2013). Correlates of estuarine survival of Atlantic salmon post-smolts from the Southern Upland, Nova Scotia, Canada. Can. J. Fish. Aquat. Sci. 70(3): 452-460. doi: 10.1139/cjfas-2012-0287

2. Halfyard, E.A., Ruzzante, D.E., Stokesbury, M.J.W., Gibson, A.J.F. and Whoriskey, F.G. (2012). Estuarine Migratory Behaviour and Survival of Atlantic Salmon Smolts from the Southern Upland, Nova Scotia, Canada. J. Fish Biol. 81: 1626–1645. doi:10.1111/j.1095-8649.2012.03419.x

1. O'Dor, R., M. Stokesbury, P.G. Amiro and **E. Halfyard.** (2008). The Ocean Tracking Network – Cutting Edge Technology on a Global Scale. J. Ocean Tech. 3(2): 23-26.

PUBLICATIONS IN PREPARATION

A. Sterling, S.M., Beerling, D.J., Keys, K., Taylor, L.L., Hart, K., and **Halfyard, E.A.** (*In Review*). The possibility of enhanced weathering to promote CO_2 sequestration and storage while increasing forest and freshwater health, productivity, and resilience. Target (Spring 2022). Nature Comm.

B. Sterling, S.M., Halfyard, E.A., Hart, K., Trueman, B., Grill, G., Lehner, B., Campbell, J., and Rønning, J.. (*In Review*). River Alkalinity Enhancement: a New CO_2 Removal Strategy. Nature Climate Change.

C. Colborne, S.F., Kessel, S.T., **Halfyard, E.A.,** & Fisk, A.T. (*In Review*). Habitat use and inter-annual site fidelity of two predatory freshwater fish in a channelized river system. Can. J. Fish. Aquat. Sci.

D. Hart, K., Trueman, B., Halfyard, E.A**.,** and Sterling, S.M. (*In Review*). Detection and prediction of toxic aluminum concentrations in high priority salmon rivers in Nova Scotia. Environmental Toxicology and Chemistry.

E. Hart, K., Halfyard, E.A., Keys, K., and Sterling, S. (*In Review*). Application of dolomite to forested catchments in Nova Scotia improves water quality - but more is needed to meet water quality targets. Science of the Total Environment. American Chemical Society environmental science and technology water

F. McCavour, C., Halfyard, E.A., Keys, K., and Sterling, S. (*In Prep.*) Early effects of helicopter liming on soil and vegetation in two acidified forest stands in Nova Scotia, Canada. Target (Spring 2022). Can. J. Forest Res.

G. Halfyard, E.A., Whoriskey, F., Daniels, J., Carr, J., Kocik, J. & Jonson, I. (*In Prep.*). Evaluating the potential of open-ocean acoustic tracking of Atlantic salmon post-smolts: A modelling approach. Target (Summer 2024). Can. J. Fish. Aquat. Sci.

H. Halfyard, E.A., Gibson, A.J.F., Keyser, F. and Whoriskey, F.G. (*In Prep.)* Within river movements of wild and supportively-reared Atlantic Salmon in the St. Mary's River, NS, CAN. Target (Fall 2022). J. Fish Biol.

I. Halfyard, E.A., Gibson, A.J.F., Keyser, F. and Whoriskey, F.G. (*In Prep.)* The movement of Atlantic Salmon in search of riverine thermal refugia. Target (Fall 2022). Can. J. Fish. Aquat. Sci.

J. Halfyard, E.A., Gibson, A.J.F., Ruzzante, D.E. and Whoriskey, F.G. (*In Prep.)* Potential impact of predators on the estuarine survival of anadromous salmonids in Nova Scotia's Southern Upland. Target (tbd): N. Am. J. Fish. Mgmt.

K. Halfyard, E.A. (*In Prep.)* Shift happens: A review of the impact of ecosystem regime shift on Atlantic salmon. Target (tbd). Reviews Fish Biol. Fisheries.

L. Broome, J.E., E.A. Halfyard, R.G. Bradford, M.J.W. Stokesbury and A.M.. Redden. (*In Prep.)* Detection range and efficiency of passive acoustic telemetry at a tidal-energy test site: Minas Passage, Bay of Fundy. Target (tbd): Animal Biotelemetry.

OTHER SELECTED LITERATURE

Halfyard, E.A. (2014). The Estuarine and Early Marine Survival of Atlantic Salmon: Estimation, Correlates and Ecological Significance. PhD Thesis. Dalhousie University, Halifax, Nova Scotia, Canada.

Redden, A.M, Broome, J., Keyser, F., Stokesbury, M.J.W., Bradford, R., Gibson, A.J.F., Halfyard, E.A. (2014). Use of animal tracking technology to assess potential risks of tidal turbine interactions with fish. Proceedings of the 2nd International Conference on Environmental Interactions of Marine Renewable Energy Technologies (EIMR2014), 28 April – 02 May 2014, Stornoway, Isle of Lewis, Outer Hebrides, Scotland.

Redden, A.M, Stokesbury, M.J.W., Broome, J., Keyser, F., Gibson, A.J.F., Halfyard, E.A., McLean, M., Bradford, R., Dadswell, M., Sanderson, B. and R. Karsten. (2014). Acoustic tracking of fish movements in the Minas Passage and FORCE demonstration area: pre-turbine baseline studies (2011-2013). Report to the Offshore Energy Research Association of Nova Scotia and the Fundy Ocean Research Centre for Energy. Acadia Centre for Estuarine Research Technical Report 118.

Halfyard, E.A., and Bradford, R.G. (2014). Survival estimates for Shubenacadie River Striped Bass (*Morone saxatilis*) derived from detections of implanted acoustic transmitters. DFO Can. Sci. Advis. Sec. Res. Doc. 201X/nnn. vi + xx p.

Bradford, R.G., Halfyard, E.A., Hayman, T., and LeBlanc, P. (2013). Overview of Bay of Fundy Striped Bass Biology and General Status. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/nnn. vi + xx p.

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Leblanc, J.E. and E.A. Halfyard. (2008). Preliminary Report on Mercury and Arsenic Contamination of Fish Tissues and the Influence of Historic Gold Mines in Nova Scotia. Technical Report. Inland Fisheries Division, Nova Scotia Department of Fisheries and Aquaculture. Pictou, Nova Scotia. 44 pp.

Halfyard, E.A. (2007). The West River, Sheet Harbour Acid Mitigation Project. *In* Brylinsky, M. and L. Hinks (*Eds*), Proceedings from the Acid Rain Mitigation Workshop, Bedford Institute of Oceanography, Nova Scotia, Canada, May 26-27, 2007. p: 83-89.

SELECTED PROFESSIONAL PRESENTATIONS *(2011-present only)*

2020-2021 – COVID HIATUS	
Atlantic Salmon Recovery and Conservation Forum, Bergen, Norway	2019
Atlantic Salmon Ecosystems Forum, Quebec, PQ	2019
Atlantic Salmon Ecosystems Forum, Bangor, ME	2018
Dalhousie Biology 'FISH' Seminar Series	2018
Project 'SHARE' Salmon Habitat Enhancement Forum	2018
St. Francis Xavier University Biology Departmental Seminar, Antigonish, NS	2018
Fisheries and Aquaculture Ministers Conference Plenary	2018
[Keynote] American Fisheries Society, Atlantic International Chapter AGM, White Point, NS	2017
Canadian Conference for Freshwater Fisheries Research, Montreal, PQ	2017
DFO Atlantic Salmon Advisory Committee Ministerial Meetings	2017
Great Lakes Fisheries Commission, Ann Arbour, Michigan, USA	2016
Biotelemetry Training Workshop [co-lead] Ontario Ministry of Natural Resources and Forestry, Glenora, ON	2016
International Fish Telemetry Conference, Halifax, Ont.	2015
Canadian Conference for Freshwater Fisheries Research, Ottawa, Ont.	2015
American Fisheries Society, AGM, Quebec City, PQ	2014
Ocean Tracking Network Canada Symposium, Ottawa, Ont.	2014
Guest Lecturer, Applied Field Methods in Fish Ecology (Dalhousie U.)	2014
Acadia University, Biology Lecture Series, Wolfville, NS	2013
Guest Lecturer, Aquatic Ecology (Acadia U.)	2013
Guest Lecturer, Applied Field Methods in Fish Ecology (Dalhousie U.)	2013
Ocean Tracking Network Canada Symposium, Halifax, NS	2012
American Fisheries Society, AGM, Seattle, WA, USA	2011
Acadia University, Biology Lecture Series, Wolfville, NS	2011

Additionally: 10-30 public lectures annually, including ENGO meetings, AGMs, working group meetings, industry groups, Chamber of Commerce meetings, outdoor sporting shows, schools etc.

ADDITIONAL QUALIFICATIONS / ACHIEVMENTS

Computing platforms: R, MARK, and most standard Microsoft programs	Current
Electrofishing certification – Malaspina University, Nanaimo, BC	Current
MEDA3, SVOP, PCOC	Current
Current Canadian Council on Animal Care Fish Stream Certified	2009
Slocum sea glider pilot training	2008

MANUSCRIPT REVIEW

Canadian Journal of Fisheries and Aquatic Sciences (6), Environmental Biology of Fishes (3), Animal Biotelemetry (1), Method in Ecology and Evolution (1), Journal of Fish Biology (3), North American Journal of Fisheries Management (2).

This is **Exhibit "B"** referred to in the affidavit of
Dr. Edmund Halfyard, affirmed before me this
19th day of January, 2024.

[redacted]

Sarah McDonald
A commissioner of the
Supreme Court of Nova Scotia

Sarah McDonald
Barrister, Solicitor, Notary Public
and a Commissioner of Oaths
in and for the Province of Nova Scotia

CHAPTER 10 - WATERSHED STEWARDSHIP PLAN – MEDWAY RIVER

10.1 WATERSHED OVERVIEW AND NATURAL HISTORY

Medway River watershed covers an area of 149,886 hectares and it is located in Queens County, on the southwestern shore of Nova Scotia, Canada. The watershed encompasses several communities including Mill Village, Charleston, Greenfield and Caledonia (Figure 10.1). These communities are approximately 15 minutes from the town of Liverpool and 20 minutes from the town of Bridgewater (the largest shopping and commercial center in the region). The main economic activities within the watershed are logging and lumber industries, fishing, and tourism.

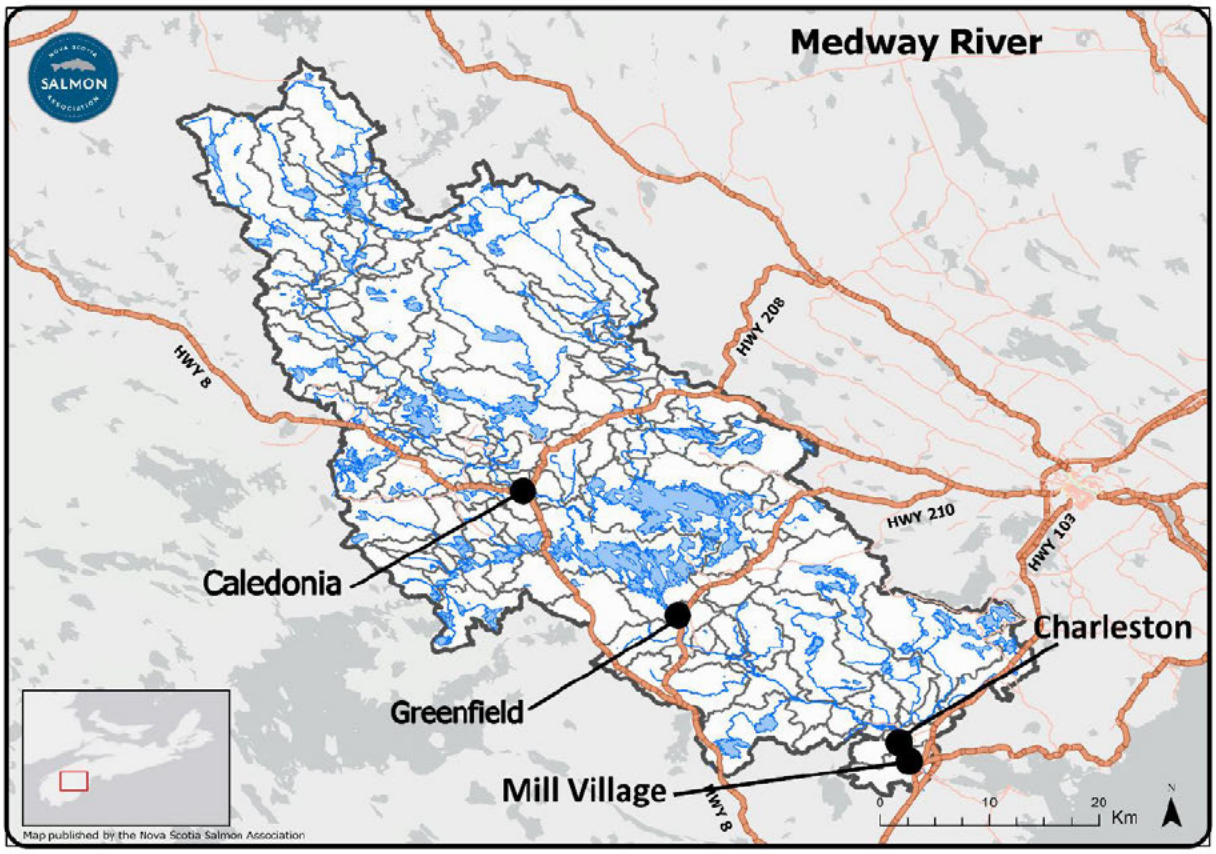

Figure 10.1 - Overview of the Medway River watershed showing local main roads, communities, the watershed boundary, and the major waterways.

The region has a mild humid continental climate with influence of the Atlantic Ocean. The average temperatures in the region range from −4.6°C in January to +18.3°C August (Canadian Climate Normals 1971–2000). The annual average precipitation is 1435 mm. The river has 121 km long and its headwaters is in the Medway Lakes Wilderness Area that is one of the largest wilderness areas in the province. The wilderness area is covered with hardwood and mixed forest hills, conifer flats, and several wetlands, waterways, and lakes. The main river is characterized by a series of pool drops, a few continuous rapids and different riverine wetlands including fens, bogs, wet meadows, seasonally flooded areas, and swamps (McKendry 2008).

The Medway River watershed is part of the Meguma geologic formation, which is composed with sedimentary rocks, drumlins and eskers resulting in hummocky terrain (AGS 2001). Elevation throughout the watershed is generally low with a maximum elevation of only 264m above sea level, however the majority of the watershed lies below 100m above sea level (Figure 10.2). Further, much of the elevation change in the lower portion of the river occurs across bedrock outcroppings that create rapids and small waterfalls (figure 10.3).

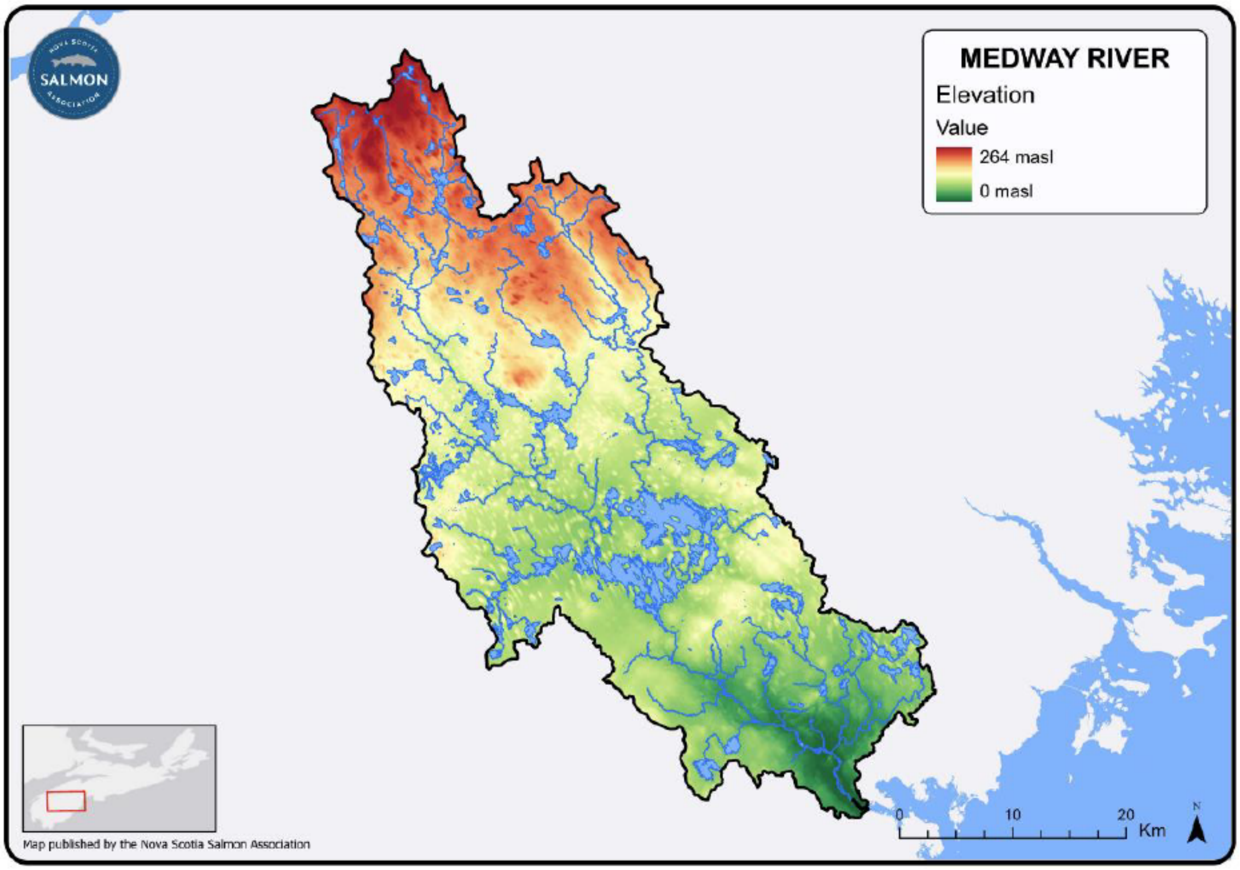

Figure 10.2 – Digital elevation model of the Medway River watershed highlighting the low maximum elevation change, particularly for the lowermost 75% of the watershed.

Figure 10.3 – Images of Mill Pool falls (left) and Bear falls (right) show typical bedrock outcropping in the river and associated rapid change in elevation. Photo credits: Benoit Lalonde photography.

The Medway watershed is an important area for conservation as the watershed is home of several species at risk including Atlantic Salmon, American Eel, (NSDNR 2007). In contrast, there are over 34 dams that pose a threat to aquatic fauna in particular the species at risk (McKendry 2008). We divided the watershed into 105 spatial planning units to make restoration assessments and recommendations at a manageable scale (Table Y; Figures 4, 5, 6, and 7). A total of 49 SPUs were classified as main spatial planning units and 56 SPUs as tributary units (Figure 4). The watershed covers a total area of 149886 hectares (ha) and the average size of SPUs was 1427 hectares. The larger SPU covers an area of 7906 hectares, while the smaller SPU is 101 hectares.

Table 10.1 Spatial Planning Units (SPUs) within the Medway River watershed. SPU type represents main river units (MU) or Tributary Planning Units (TPU). Stream order is based on Strahler stream order classification. Latitude and Longitude represents a location within each of the 105 SPUs.

Local names	SPU number	SPU type	Longitude	Latitude	Stream order	SPU area (ha)
Alma Lake	1	MU	-65.111900	44.619698	4	989
East Branch Medway River	2	MU	-65.104180	44.584866	4	422
Medway Lake	3	MU	-65.115224	44.570088	4	965
East Branch Medway River	4	MU	-65.122711	44.545881	4	334
West Branch Medway River	5	MU	-65.143830	44.540464	4	209
Pleasant River Lake	6	MU	-64.926734	44.525989	4	1040
Upper Medway River	7	MU	-65.123057	44.513523	5	699
Pleasant River	8	MU	-64.898897	44.497182	4	202
Upper Medway River	9	MU	-65.107529	44.485692	5	408
Medway River at New Albany	10	MU	-65.088821	44.469212	5	539
Pleasant River	11	MU	-64.884730	44.446563	4	361
McGowan Lake	12	MU	-65.055902	44.440858	5	1845
Tupper Lake	13	MU	-64.992850	44.445486	4	3690
Medway River, Megher	14	MU	-65.032525	44.404178	5	454
Pleasant River	15	MU	-64.894556	44.409155	5	290
Medway River, Megher	16	MU	-65.058091	44.415092	5	218
Medway River, South Brookfield	17	MU	-64.974224	44.380354	5	252
Medway River, Caledonia	18	MU	-65.010346	44.387990	5	227
Medway River, South Brookfield	19	MU	-64.954631	44.375107	5	543
Molega Lake	20	MU	-64.845238	44.360269	5	7783
Christopher Lakes	21	MU	-64.992933	44.317316	5	961
Ponhook Lake	22	MU	-64.887307	44.316586	6	6692
Lower Main Medway	23	MU	-64.824172	44.236697	6	488
Lower Main Medway (Greenfield)	24	MU	-64.838438	44.258199	6	893
Lower Main Medway (Poltz Falls)	25	MU	-64.709689	44.187108	6	566
Lower Main Medway (Salters Falls)	26	MU	-64.655983	44.174040	6	522
Lower Main Medway (Riversdale)	27	MU	-64.685705	44.178862	6	245
Lower Main Medway (Glode Falls)	28	MU	-64.772881	44.216395	6	1249
Lower Main Medway (Mill Village)	29	MU	-64.668549	44.144756	6	1618
Petite Brook	30	MU	-64.638004	44.190826	4	582
Lower Salters Brook	31	MU	-64.661481	44.187627	4	116
Pleasant River	32	MU	-64.884801	44.471567	4	383
Upper Medway River	33	MU	-65.130519	44.531175	5	367

Table 10.1 Continued. Spatial Planning Units (SPUs) within the Medway River watershed. SPU type represents main river units (MU) or Tributary Planning Units (TPU). Stream order is based on Strahler stream order classification. Latitude and Longitude represents a location within each of the 105 SPUs.

Local names	SPU number	SPU type	Longitude	Latitude	Stream order	SPU area (ha)
Pleasant River	34	MU	-64.884830	44.485702	4	567
Pleasant River	35	MU	-64.883959	44.460327	4	325
Pleasant River	36	MU	-64.875035	44.412016	5	531
Pleasant River	37	MU	-64.873601	44.428245	4	101
Westfield River	38	MU	-64.989843	44.405729	4	373
Lower Main Medway	39	MU	-64.794355	44.232980	6	123
Medway River, South Brookfield	40	MU	-64.991957	44.383493	5	196
Pleasant River	41	MU	-64.910694	44.509574	4	312
Cole Brook / Russell Lake	42	MU	-65.034494	44.342064	4	982
Christopher Lakes	43	MU	-65.012476	44.305658	5	601
Telfer Lake	44	MU	-65.037435	44.306554	2	482
Christopher Lakes	45	MU	-64.977562	44.343948	5	874
Lower Main Medway	46	MU	-64.739238	44.192563	6	665
Mouth of Pleasant River	47	MU	-64.881183	44.392778	5	225
Lower Main Medway (Bangs Falls)	48	MU	-64.826121	44.251165	6	318
Shingle Lake	49	MU	-64.840835	44.421332	4	1033
Donnelly Brook	50	TPU	-65.131324	44.678066	3	3354
Birch Bridge Brook	51	TPU	-65.149626	44.647723	2	1269
Cranberry Brook	52	TPU	-65.086438	44.617833	2	701
Randolphs Stream	53	TPU	-65.164667	44.635114	3	2879
Mitchell Brook	54	TPU	-65.069174	44.591582	2	1045
Unnamed Brook	55	TPU	-65.081391	44.563705	2	809
Bog Brook / West Branch Medway River	56	TPU	-65.195036	44.620292	3	5766
Unnamed	57	TPU	-65.169355	44.553761	3	838
Upper Wildcat River	58	TPU	-64.969369	44.585934	3	7251
Snowshoe Lakes	59	TPU	-65.168061	44.529774	2	812
Dexter Brook	60	TPU	-64.894916	44.545739	3	2116
Luxtons Meadow Brook	61	TPU	-65.150813	44.505857	2	953
Beaver Brook	62	TPU	-64.957961	44.523921	3	1495
Porcupine Brook	63	TPU	-65.081599	44.522393	3	3000
Moose Pit Brook	64	TPU	-65.047122	44.490543	3	1756
Smith Meadow Brook	65	TPU	-64.913200	44.475978	2	528
Mill Brook / Mill Lake	66	TPU	-65.147320	44.478329	3	2196
DeLong Lake	67	TPU	-65.097252	44.449649	2	525

Table 10.1 Continued. Spatial Planning Units (SPUs) within the Medway River watershed. SPU type represents main river units (MU) or Tributary Planning Units (TPU). Stream order is based on Strahler stream order classification. Latitude and Longitude represents a location within each of the 105 SPUs.

Local names	SPU number	SPU type	Longitude	Latitude	Stream order	SPU area (ha)
Halfway Brook and Round Lake Brook	68	TPU	-64.996728	44.513307	3	7906
Deep Brook	69	TPU	-64.862955	44.444597	2	537
Mount Merrit Brook	70	TPU	-65.114850	44.440288	3	1255
Black Brook and Meadow Brook	71	TPU	-64.910777	44.445600	3	1254
Shingle Lake	72	TPU	-64.784587	44.409087	3	2661
Back Hill Brook	73	TPU	-65.013070	44.422822	3	386
Horse Lake	74	TPU	-64.973618	44.402798	2	596
Hog Lake Meadow Brook	75	TPU	-64.916779	44.413647	3	1097
Harmony Lake	76	TPU	-65.102668	44.398878	3	2365
Doyles Cove Brook	77	TPU	-64.792602	44.383535	2	592
Unnamed Brook / Lakeview	78	TPU	-65.057890	44.384920	3	1839
Beaver Brook / Faulkenham Brook	79	TPU	-64.940122	44.396574	2	1322
Charlotte Lake / Mary Lake	80	TPU	-64.992380	44.371937	2	1145
Whiteburn Brook	81	TPU	-65.084137	44.349969	3	2262
Hanley Brook	82	TPU	-64.752190	44.356251	3	2202
Meagher Brook	83	TPU	-65.009795	44.346380	2	825
Red Brook	84	TPU	-65.068663	44.328791	3	404
Unnamed Tributary, Whiteburn Mines	85	TPU	-65.033835	44.299581	4	537
Browns Brook	86	TPU	-64.773560	44.315740	2	939
McBride Brook	87	TPU	-65.073331	44.304701	3	1053
Beartrap Brook	88	TPU	-64.961246	44.299897	3	1254
Kendron Brook	89	TPU	-64.808500	44.293701	2	926
Eighteen Mile Brook	90	TPU	-64.914069	44.279478	3	2305
Bull Moose Brook	91	TPU	-65.017591	44.272300	3	2007
Buggy Hole Brook	92	TPU	-64.805419	44.255944	2	573
Dean Brook	93	TPU	-64.779862	44.256735	3	1547
Fifteen Mile Brook	94	TPU	-64.880080	44.247952	2	1497
Wentworth Brook	95	TPU	-64.735274	44.247103	3	3908
Oakes Mill Brook	96	TPU	-64.633402	44.255939	3	5393
Murray Brook	97	TPU	-64.840151	44.215021	3	2816
Petite Brook	98	TPU	-64.589103	44.223190	3	1900
Glode Meadow Brook	99	TPU	-64.682190	44.200500	2	893

Table 10.1 Continued. Spatial Planning Units (SPUs) within the Medway River watershed. SPU type represents main river units (MU) or Tributary Planning Units (TPU). Stream order is based on Strahler stream order classification. Latitude and Longitude represents a location within each of the 105 SPUs.

Local names	SPU number	SPU type	Longitude	Latitude	Stream order	SPU area (ha)
Salters Brook	100	TPU	-64.703603	44.277781	3	6222
Otter Pond Brook	101	TPU	-64.727978	44.170672	2	548
Tummblingdown Brook	102	TPU	-64.685438	44.160007	2	647
Two Inch Brook	103	TPU	-64.790667	44.175183	3	2903
Unnamed Tributary, Westfield	104	TPU	-65.015313	44.409207	3	384
Barren Meadow Brook and Keddy Brook	105	TPU	-64.822938	44.445935	3	1833

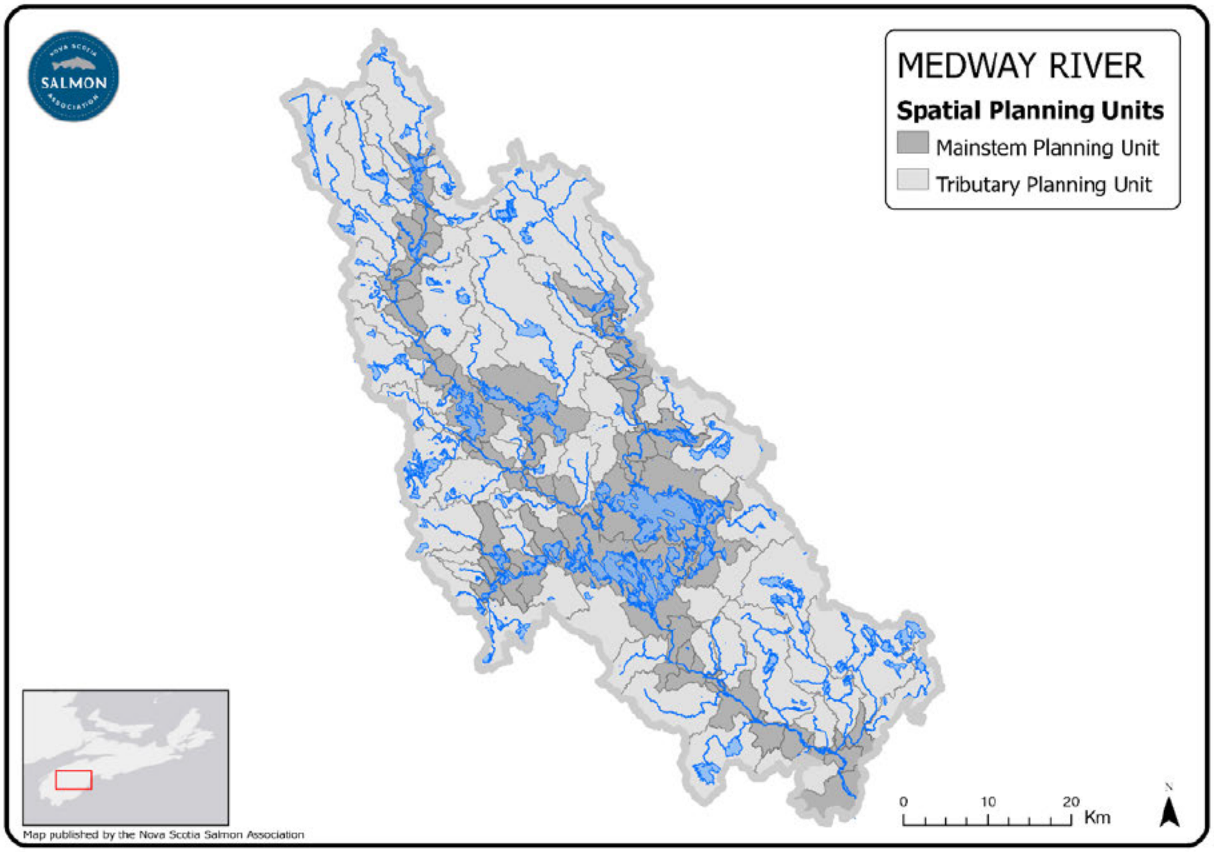

Figure 10.4 - The Medway River watershed divided into 105 spatial planning units, including mainstem units (dark grey) and tributary planning units (light grey).

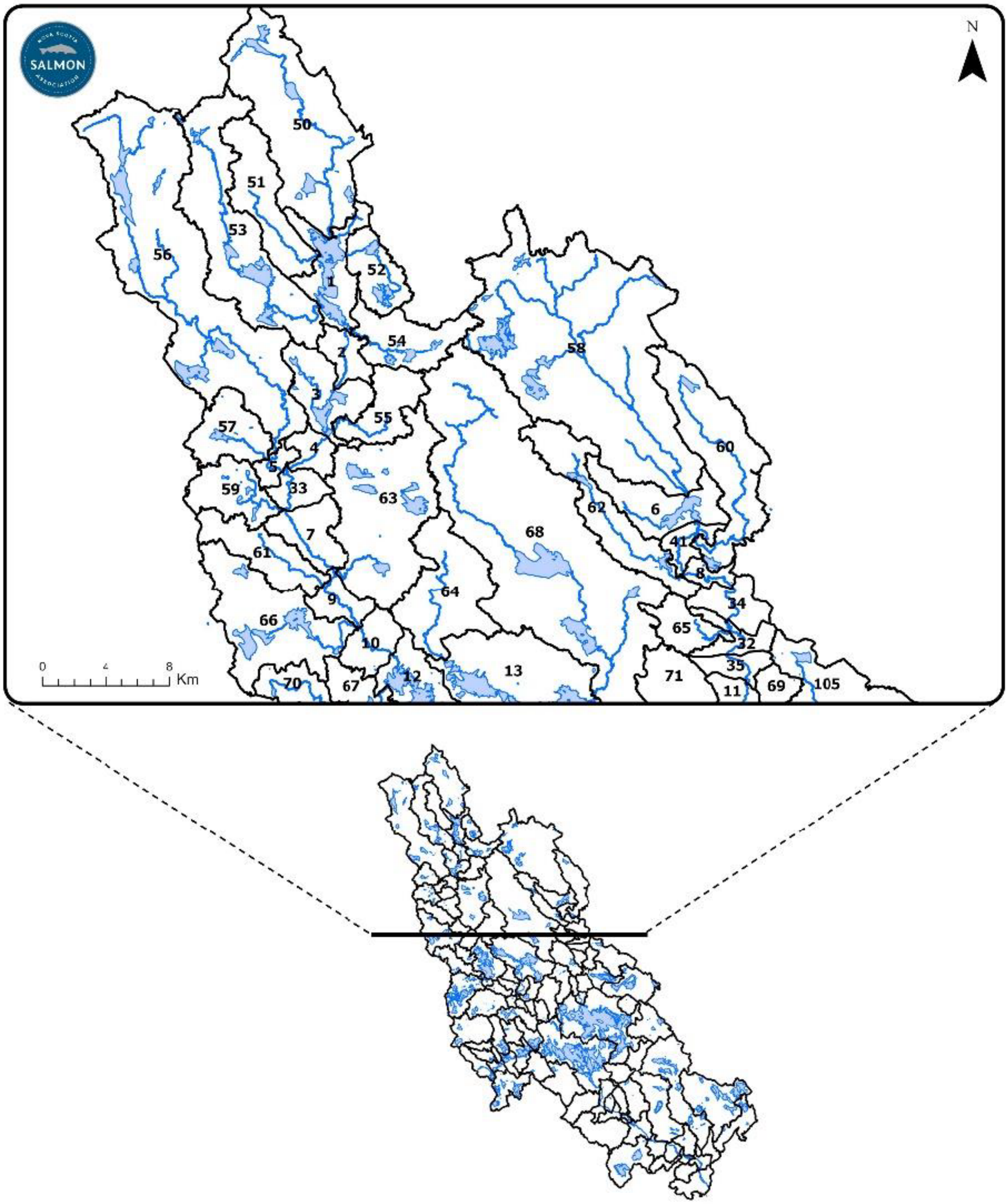

Figure 10.5 – Detailed overview of the spatial planning units within the Medway River watershed with focus on the upper third of the watershed.

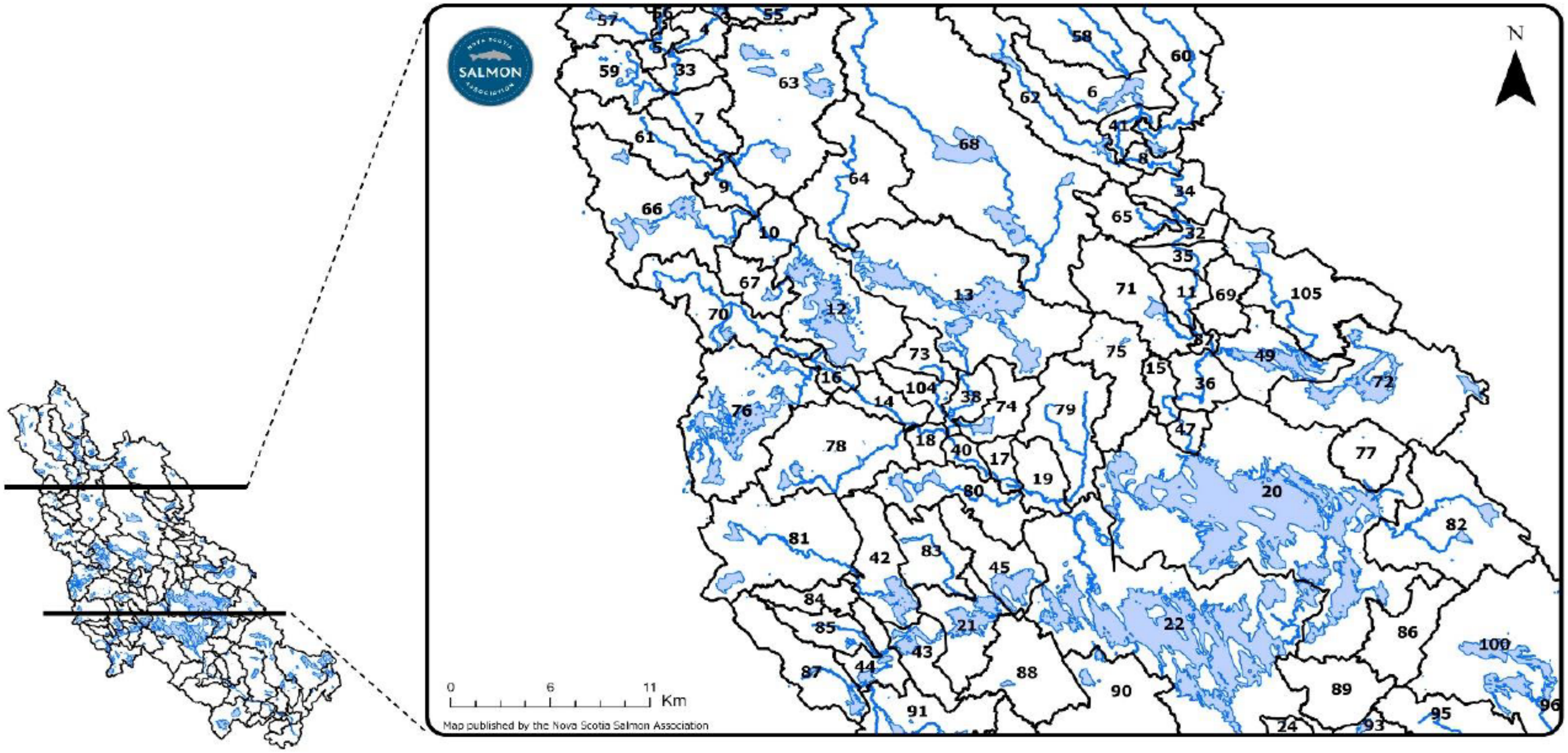

Figure 10.5 – Continued. Detailed overview of the spatial planning units within the Medway River watershed with focus on the middle third of the watershed.

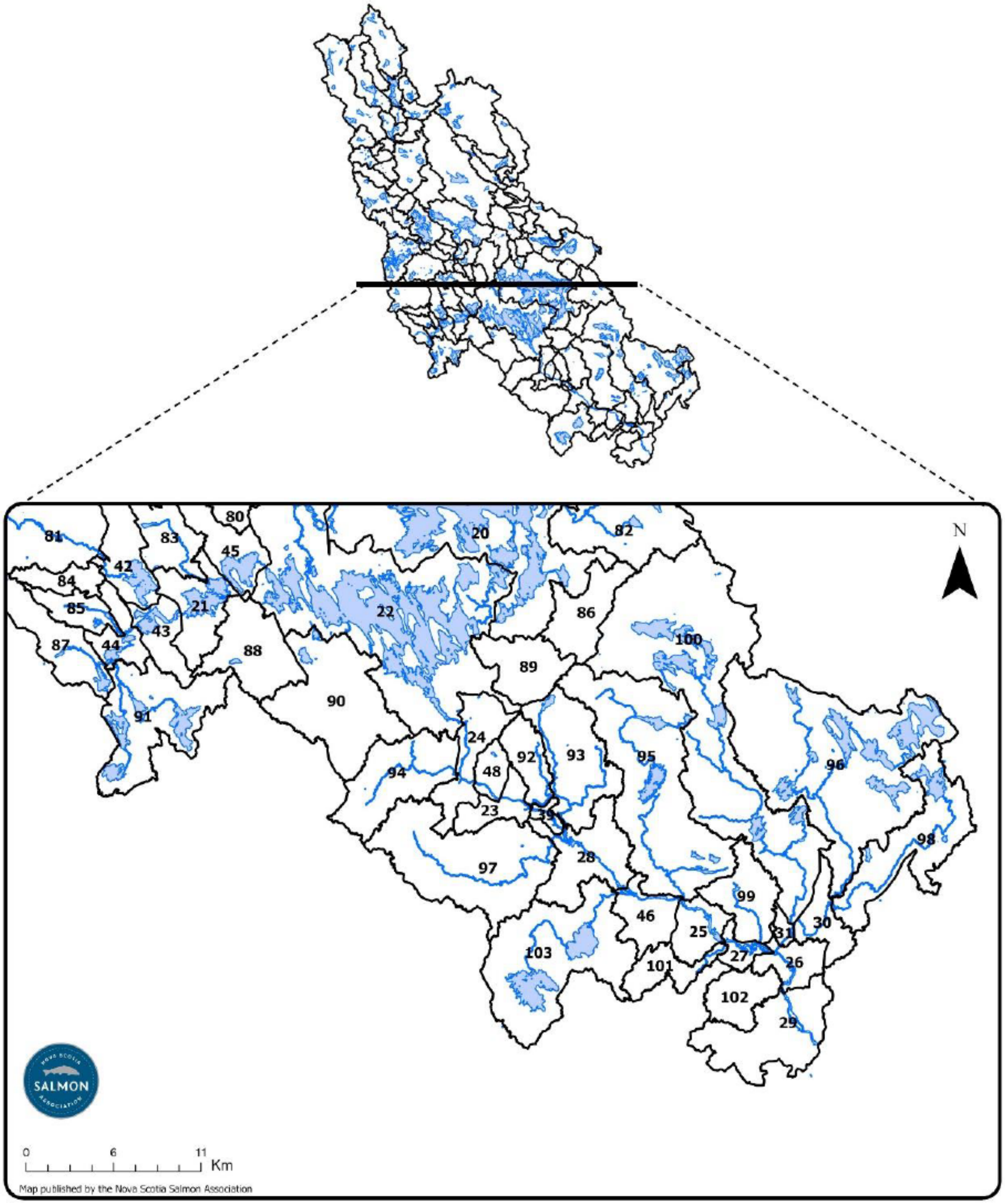

Figure 10.5 – Continued. Detailed overview of the spatial planning units within the Medway River watershed with focus on the lower third of the watershed.

The bedrock geology within the Medway River watershed is composed of metamorphic rocks (greywacke, quartzite and slate) in the central and southern portions of the watershed, while the northern portion is composed of igneous rocks (granite, diabase, and gabbro) (Figure 10.6).

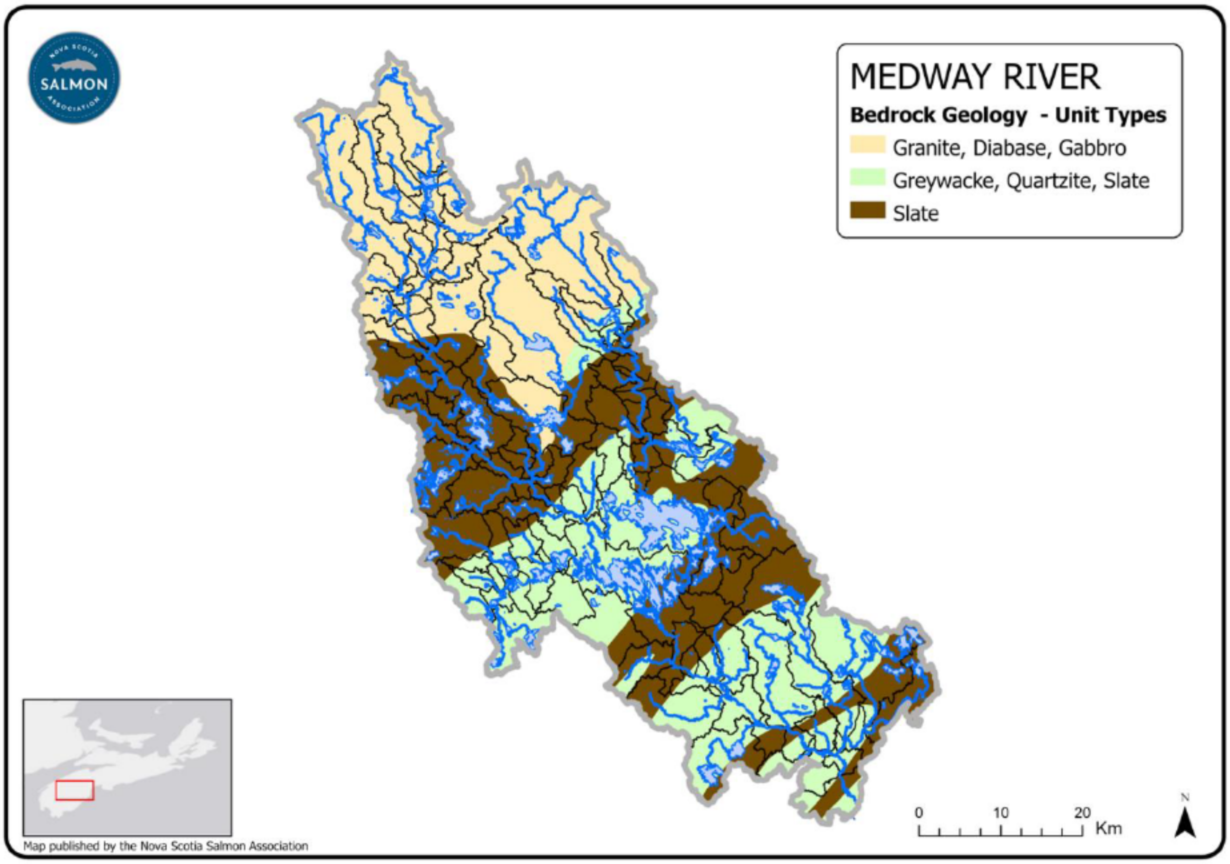

Figure 10.6 - Bedrock geology of the Medway River watershed in the southwestern shore of Nova Scotia, Canada.

The dominant surficial geological formation in the watershed is the Ground Morraine and Streamlined Drift (Figure 10.7). There are small patches of organic and glaciofluvial deposits scattered thought the watershed. There is a single small patch of alluvial deposits in a tributary in the northern portion of watershed, whereas bedrock outcrops are found in large sections of the eastern portion of the watershed. Glaciofluvial deposits are found at the mouth of the main channel (Figure 10.7).

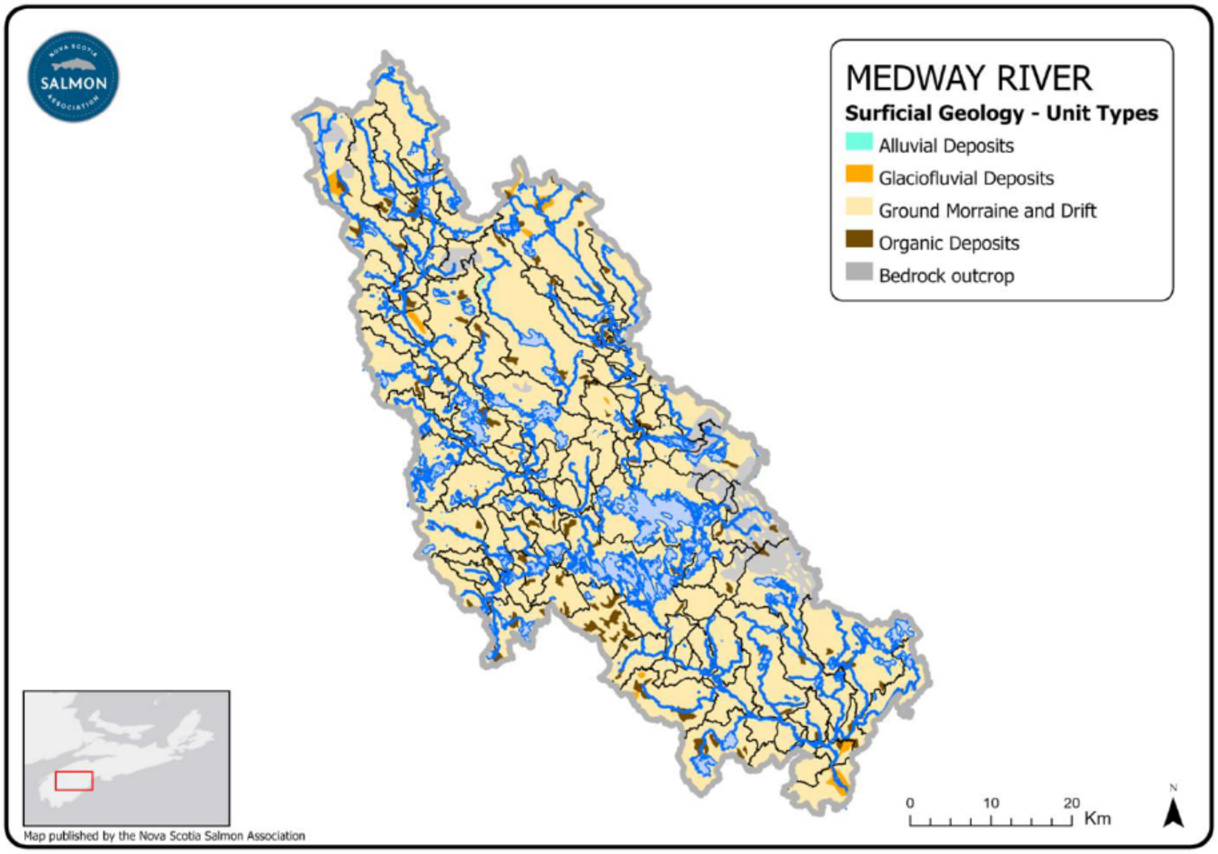

Figure 10.7 - Surficial geology of the Medway River watershed in the southwestern shore of Nova Scotia, Canada.

Nova Scotia is situated within the Acadian Forest region which is primarily characterized by the dominance of red spruce (*Picea rubens*) and yellow birch (*Betula alleghaniensis*) trees (Rowe 1972). Although less abundant black spruce (*Picea mariana*), balsam fir (*Abies balsamea*) maple (Acer ssp.) trees are also commonly found. In this context, hardwood, softwood and mixedwood forests are composed with different proportions of the species highlighted above.

In the Medway River watershed, softwood forests covered 53.7% of the total area of the watershed, followed by mixedwood forest with 22.8 %, and hardwood forests with 3.8% (Figure 10.8). The mixedwood and hardwood forest stands well distributed throughout the watershed.

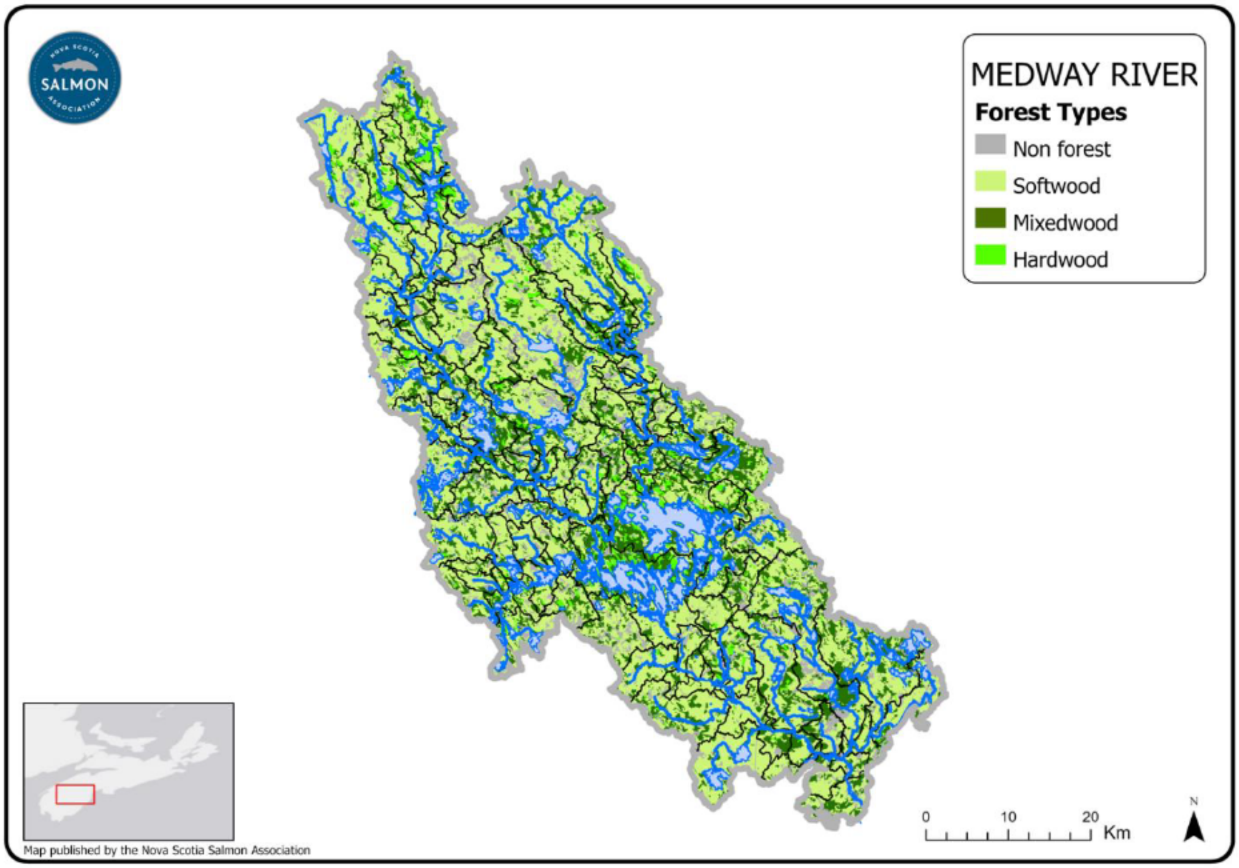

Figure 10.8 Forest types that compose the Medway River watershed in the southwestern shore of Nova Scotia, Canada.

Thirty land use types were mapped in both sub watersheds including multiple types of forests and wetlands. We grouped the 30 land use types into 10 land use type groups for simplicity and easy visualization in the land use maps (Figure 10.9). The 10 land use categories are: Forest stand, Silviculture, Clear cut, Wetlands, Barrens, Agriculture, Urban, Road corridor, gravel pit and Water bodies.

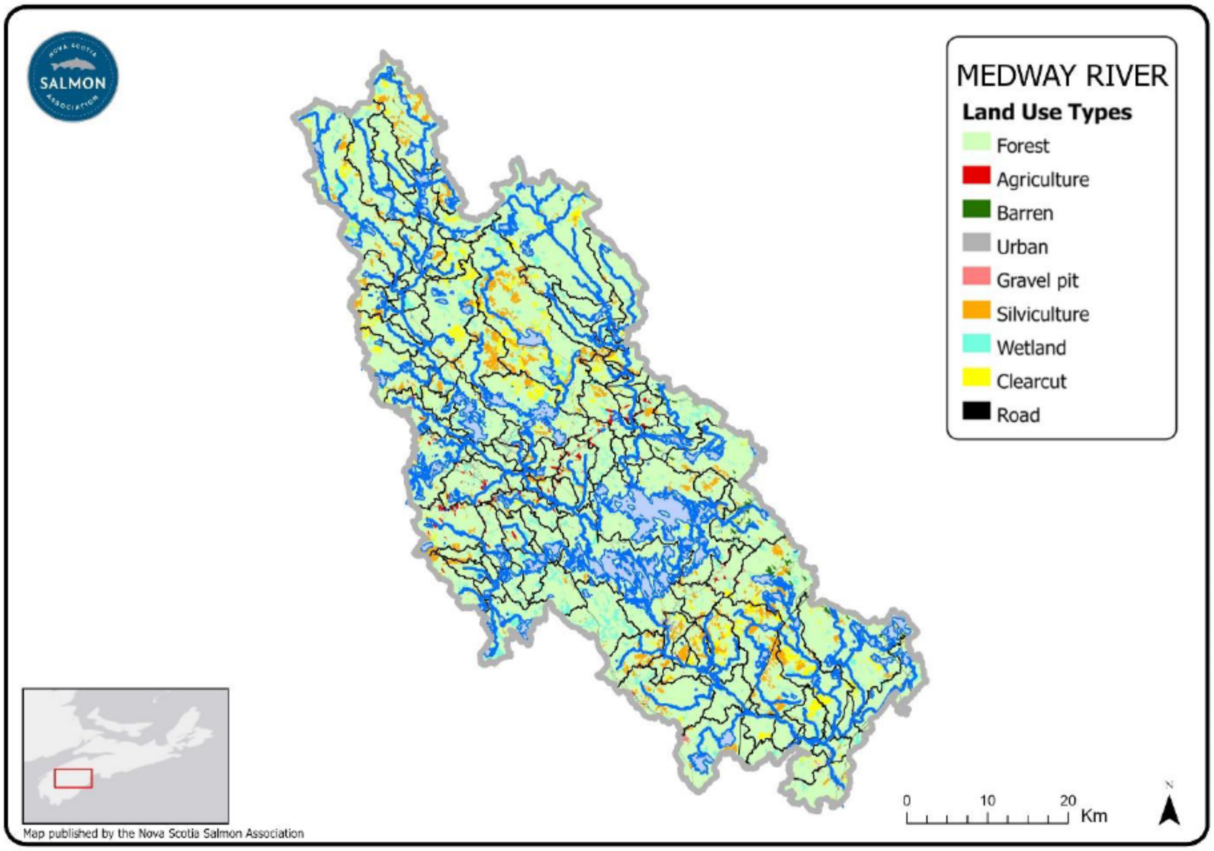

Figure 10.9 Land use map of the Medway River watershed in the southwestern shore of Nova Scotia, Canada. The land use water bodies are represented by rivers and lakes.

The watershed is mainly covered by forests that encompass 75 % of the total area of the watershed. Water bodies (rivers and lakes) covered 8.2% of the total area, followed by wetlands (6.6%), silviculture (4.8%), and clearcut (3.1%). The remaining land use groups: Barrens, Agriculture, Urban, Gravel pit, and Roads covered together only 2.4% of the total area (Table 10.2). Clearcuts and silviculture stands are distributed across the watershed, while agriculture and urban areas are concentrated along the roads in the middle and lower portion of the watershed. Lakes and wetlands are abundant throughout the watershed.

Table 10.2- Summary table of the land use groups mapped in the boundaries of the Medway River watershed in eastern shore, Nova Scotia. Total area (%) means the percentage of total area of the watershed covered by each of the land use types.

Land use type	Total area (%)
Agriculture	0.9
Barren	0.01
Clearcut	3.1
Forest stand	75.0
Gravel pit	0.1
Road	0.6
Silviculture	4.8
Urban	0.8
Water bodies	8.2
Wetland	6.6

10.2 STATE OF THE WATERSHED

10.2.1 Community and local knowledge summary

In the Medway watershed, raw data were collected in sampling sites located at the mouth of the watershed, with only one site at the most Northern tributary (Figure 10.10A). The studied features in the research/publications conducted in Medway watershed included: brook floater study/survey, invasive species study/survey, public outreach, salmon study/survey, sediment/debris removal, site assessment, species survey, structure installation, structure repair, water quality monitoring (Figure 10.10 A).

The local community knowledge surveys resulted in five responses all recorded within the spatial planning units (Figure 10.10B). All sites were in the downstream reaches of the watershed and the information provided was related to the presence of Atlantic salmon, possible barriers, and smallmouth bass (Figure 10.10 B).

This information, along with discussions with stakeholders and rightsholders in the area, guided sampling design. Specifically, we ensured that areas with recent evidence of Atlantic Salmon as well as those with historical data were sampled. Also, we ensured that areas near and adjacent to the distribution of aquatic invasive species were sampled.

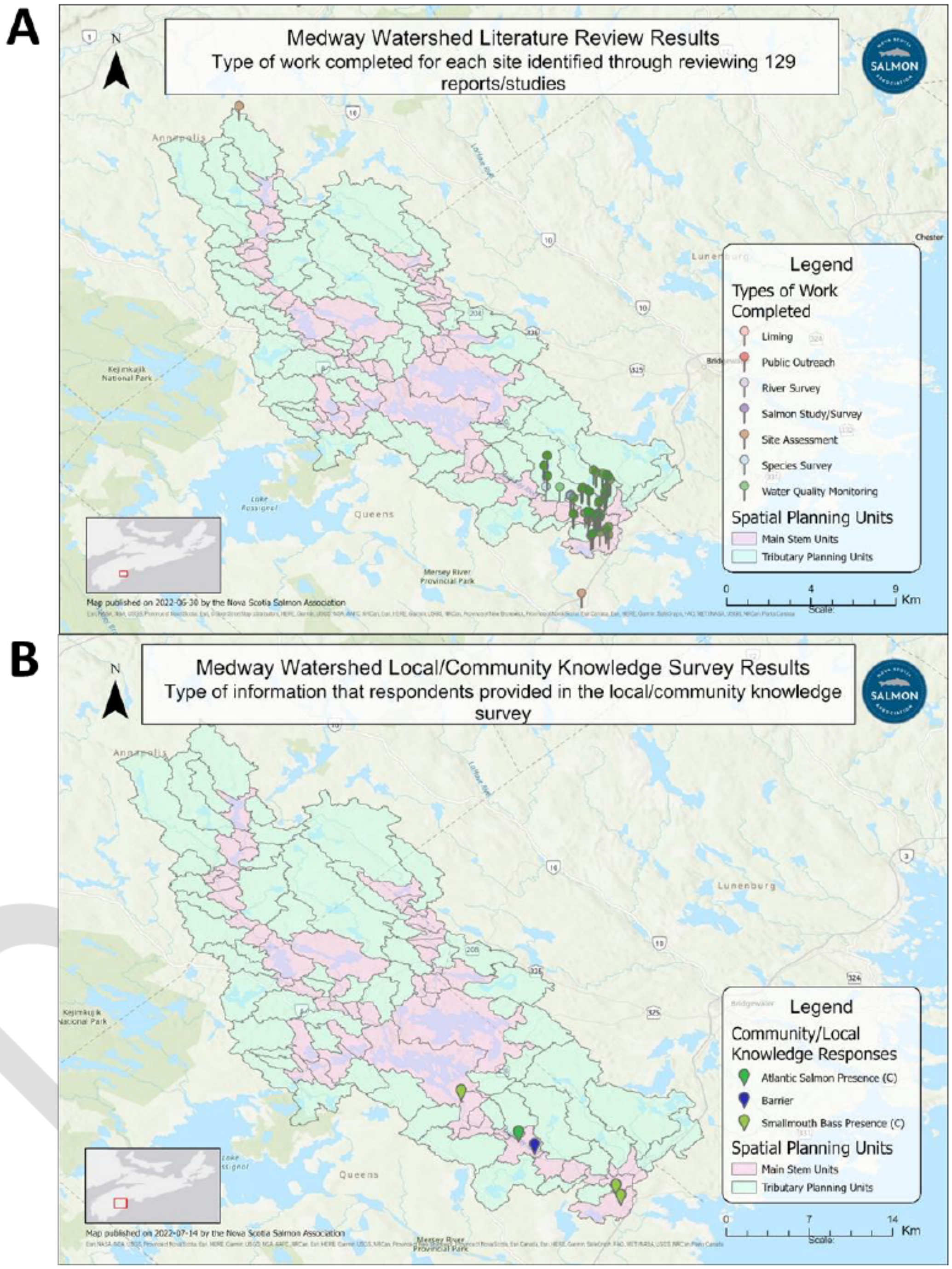

Figure 10.10 – (A) Spatial distribution and number of sampling points (pins) where raw data were collected across the Medway watershed. Pins with different colors represent the studied features within the three categories of research focus: 1 - biology and ecology of aquatic species, 2 - habitat restoration and assessment, and 3 - socio-economic factors. (B) Survey responses of local community members that provided knowledge on specific sites across the Medway watershed. Survey was developed through Survey123 and distributed throughout 2020-2021. Colours of points in both figure A and B appear darker where overlapping points occur. Spatial planning units were developed by the Nova Scotia Salmon Association as part of the Southern Uplands WATER project.

10.2.2 LiDAR-based habitat metrics

Analysis of the available LiDAR data for the Medway River provides an overview of the physical habitat characteristics of the watershed. Here are the results of this work.

Slope

Stream slope has been widely used to estimate the suitability of fluvial habitat for Atlantic Salmon. For example, following up on the work by Amiro (1993), both O'Connell et al. (1997) and Amiro (2000) estimated the total productive Atlantic Salmon habitat within the Medway River which they defined as 0.129% to 25% slope. They estimated that the Medway River had a total of 6.76 million m^2 of suitable fluvial salmon rearing habitat. For this analysis we used a more restrictive definition of 0.5% – 3.0% slope as ideal habitat, but also consider their broader definition of productive habitat.

For each SPU within the Medway River watershed, we used LiDAR data to estimate stream slope for 101,724 segments of the Medway River, each 10m in length. Across the entire watershed the average slope was 0.31% +/- 0.93 (mean +/- sd). Lakes are a dominant feature of the Medway River watershed and 81.0% of the linear length of the stream network lies within lakes that have a slope of 0% (Table 10.3) (i.e., a straight line drawn between the inlet and outlet of the lake). Removing lakes from consideration, the average slope of the Medway river habitat is 1.13% +/- 1.51. Of the non-lake habitat, 22.9% is within the ideal range of 0.5% - 3.0% and 73.9% would be considered productive salmon habitat (Table 10.3).

Instream physical habitat restoration techniques, such as deflectors, rock sills, groins and digger logs, are intended to restore geomorphological stream function, encourage groundwater-surface water exchange, facilitate healthy bedload movement and reestablish a meander pattern that is appropriate for the slope and substrate. It is the experience of the NSSA and our partners that in Nova Scotia a stream gradient of at least 1% slope is required for these instream interventions to be effective. Within the Medway River, only 22.5% of the habitat is greater than 1%.

Further, in streams where mobile sediment, such as gravel/cobble dominant substrate, researchers have long understood patterns of river meandering that seem to hold true across the globe. For example, Leopold et.al. (1964) noted that riffles were spaced 5 to 7 channel widths apart and that meander wavelengths measured 10 to 14 channel widths (as wavelengths are comprised of 2 riffle-run-pool sequences). This observation led to the development of fundamental meander geometry formulas to relate channel width measurements with linear pattern measurements (William 1986, Thorne et al. 1997).

Patterns in meander geometry are also influenced by stream substrate and by stream slope. For example, rivers with large substrate or difficult to erode material such as clay banks, streams will often have a narrower channel than expected for the size of watershed and have meander patterns that are tighter/ shorter than expected (Knighton, 1998). Within Nova Scotia, the NSSA typically observes that streams less than 2% are necessary to produce meandering at the expected 5-7:1 ratio.

Table 10.3– Summary of watershed-wide assessment of 10m long slope estimates using LiDAR. Here, lakes represent slope values of 0.00.

Slope Category	# of 10m Segments	Cumulative Percent of Habitat	Cumulative Percent of Habitat (Excl. Lakes)
>25.0%	3	0.0%	0.0%
10.0% to 24.9%	88	0.1%	0.5%
3.0% to 9.9%	2,340	2.4%	12.6%
5.5 to 3.0%	4,421	6.7%	35.5%
0.13-0.5%	7,424	14.0%	73.9%
0.01 to 0.129	5,050	19.0%	100.0%
Lake	82,398	100.0%	
Total	**101,724**		

We calculated the average slope within each SPU (Table 10.3), and the average slope of the 105 SPUs was 0.30%. The largest average slope observed in any SPU was 0.96% (SPU#92, Buggy Hole Brook, Figure X) while some SPUs that encompassed only lake and Stillwater habitat displayed average slopes of 0.00% (Table 10.3.

The average proportion of each SPU that is within the assumed suitable range for Atlantic Salmon rearing was 12.5% and among SPUs proportion of habitat that is considered salmon rearing habitat ranged from 0 to 35.8 % (Table 2, Figure 7). A total of 43/105 SPUs had less than 10% of the habitat within the suitable range for Atlantic Salmon rearing and were generally considered "poor". Another 46/105 SPUs had only 10% to 20% of the habitat within the suitable range for Atlantic Salmon rearing and were generally considered "marginal". Finally, 15/105 had 20% to 30% of the habitat within the suitable range for Atlantic Salmon rearing and were generally considered "ok". Only one PLU was considered good SPU 4, East Branch Medway), and even this is well below the expected 66% as rearing habitat expected for an ideal salmon stream. Satellite imagery of this PLU shows an abundance of large slow pools some of which at 340m in length. Therefore, this SPU consists of short, interrupted segments of habitat at the appropriate slope for salmon rearing.

Of the 16 SPUs ranked as either OK or Good (i.e., those with >20% of the habitat as ideal slope), 13/16 were TPUs (tributaries) while only 3/16 were in the main river (MSUs). Even within TPUs, much of the habitat within the ideal range of 0.5% to 3.0% occurs high up in first order streams in the upper portion of the watershed and may be difficult to access (e.g., SPU #92 (Buggy Hole Brook, Figure 10.12). This would typically be very small streams that would offer minimal habitat for salmon, but it certainly ideal for Brook Trout and other species. Fifteen Mile

Brook (SPU #92) is one of the few high-ranking SPUs with most of its suitable gradient habitat near it's confluence with the main river (Figure 10.13).
Interpreting slope data within the Medway should be done with caution. It does highlight areas which potentially have spawning and rearing habitat, but it does not mean that it is appropriate habitat. If we examine the highest ranking MSUs, it is unlikely that suitable gravel exists within the appropriately sloped habitat due to the large instream pools and upstream lakes. In this scenario, high flow events would scour gravel and small substrate from the higher slope areas and transport it downstream until the low slope pool habitats where the energy would dissipate and the bedload would fallout, resulting in an interruption of the downstream transport of gravel. This 'starves' the recruitment of gravel in the downstream habitats leaving mainly bolder and cobble as the dominate substrate. Similar bedload interruptions has been described when reservoirs are created for hydroelectric development (e.g. Collins and Dunne 1989, Kondolf 1997), albeit at a larger scale, the same dynamics apply.

Put in the context of Atlantic Salmon management and recovery, there is a high likelihood that the total amount of suitable Atlantic Salmon is considerably lower than that described by O'Connell et al. 1997 which is the basis for estimating conservation targets. The LiDAR-derived slope estimates described here can be used to refining the estimate of total suitable rearing habitat by estimating stream width at each location and incorporating information on dominant substrates.

For American Eel, the low overall slope of habitats in the Medway is not likely to affect productivity as eels occupy a diversity of freshwater habitat.

Table 10.4 - Average slope, percent of each SPU with slope between 0.5% – 3.0% and the assigned scoring category in each of the 105 spatial planning units within Medway River.

SPU ID	Average slope %	% Salmon Rearing Habitat in SPU	Scoring category
1	0.04	0.3	Poor
2	0.57	27.5	OK
3	0.02	1.2	Poor
4	0.77	35.8	Good
5	0.11	6.2	Poor
6	0.03	1.7	Poor
7	0.30	15.6	Marginal
8	0.26	15.0	Marginal
9	0.12	7.4	Poor
10	0.03	2.1	Poor
11	0.25	12.7	Marginal
12	0.01	0.1	Poor
13	0.05	3.3	Poor
14	0.09	6.2	Poor
15	0.12	5.2	Poor
16	0.36	15.4	Marginal
17	0.16	11.6	Marginal
18	0.02	0.5	Poor
19	0.08	3.5	Poor
20	0.01	0.6	Poor
21	0.03	2.0	Poor
22	0.02	0.9	Poor
23	0.37	19.2	Marginal
24	0.32	10.2	Marginal
25	0.08	5.8	Poor
26	0.15	8.1	Poor
27	0.10	6.3	Poor
28	0.18	9.5	Poor
29	0.11	5.7	Poor
30	0.29	8.3	Poor
31	0.19	8.6	Poor
32	0.19	13.8	Marginal
33	0.29	8.8	Poor
34	0.21	11.8	Marginal
35	0.28	19.6	Marginal

Table 10.4 – Continued. Average slope, percent of each SPU with slope between 0.5% – 3.0% and the assigned scoring category in each of the 105 spatial planning units within Medway River.

SPU ID	Average slope %	% Salmon Rearing Habitat in SPU	Scoring category
36	0.01	0.2	Poor
37	0.02	1.5	Poor
38	0.34	16.9	Marginal
39	0.16	7.6	Poor
40	0.09	6.2	Poor
41	0	0.2	Poor
42	0.08	5.0	Poor
43	0.04	1.9	Poor
44	0.63	24.1	OK
45	0.1	5.5	Poor
46	0.08	4.2	Poor
47	0.25	14.8	Marginal
48	0.22	17.0	Poor
49	0.01	0.2	Poor
50	0.35	13.3	Marginal
51	0.56	18.2	Marginal
52	0.36	13.0	Marginal
53	0.3	13.3	Marginal
54	0.28	8.3	Poor
55	0.46	18.4	Marginal
56	0.31	12.7	Marginal
57	0.87	24.0	OK
58	0.29	13.1	Marginal
59	0.63	13.4	Marginal
60	0.43	22.5	OK
61	0.83	22.2	OK
62	0.55	14.5	Marginal
63	0.54	10.8	Marginal
64	0.36	18.8	Marginal
65	0.4	21.8	OK
66	0.37	14.3	Marginal
67	0.27	13.0	Marginal
68	0.27	12.8	Marginal
69	0.26	14.2	Marginal
70	0.33	17.2	Marginal

Table 10.4 – Continued. Average slope, percent of each SPU with slope between 0.5% – 3.0% and the assigned scoring category in each of the 105 spatial planning units within Medway River.

SPU ID	Average slope %	% Salmon Rearing Habitat in SPU	Scoring category
71	0.41	21.0	OK
72	0.15	4.5	Poor
73	0.41	19.8	Marginal
74	0.22	13.2	Marginal
75	0.46	21.6	OK
76	0.02	8.1	Poor
77	0.74	18.6	Marginal
78	0.34	14.9	Marginal
79	0.34	17.1	Marginal
80	0.16	6.8	Poor
81	0.38	17.6	Marginal
82	0.46	18.4	Marginal
83	0.21	12.3	Marginal
84	0.00	0.0	Poor
85	0.08	3.0	Poor
86	0.79	29.1	OK
87	0.62	27.0	OK
88	0.25	12.3	Marginal
89	0.71	32.9	OK
90	0.30	12.9	Marginal
91	0.07	3.1	Poor
92	0.96	31.1	OK
93	0.60	18.9	Marginal
94	0.38	24.6	OK
95	0.30	9.9	Poor
96	0.02	6.9	Poor
97	0.39	17.3	Marginal
98	0.03	11.9	Marginal
99	0.91	17.8	Marginal
100	0.32	14.6	Marginal
101	0.70	27.7	OK
102	0.64	19.3	Marginal
103	0.29	11.0	Marginal
104	0.50	22.1	OK
105	0.22	11.8	Marginal
SPU average	**5.20**	**12.5**	**Marginal**

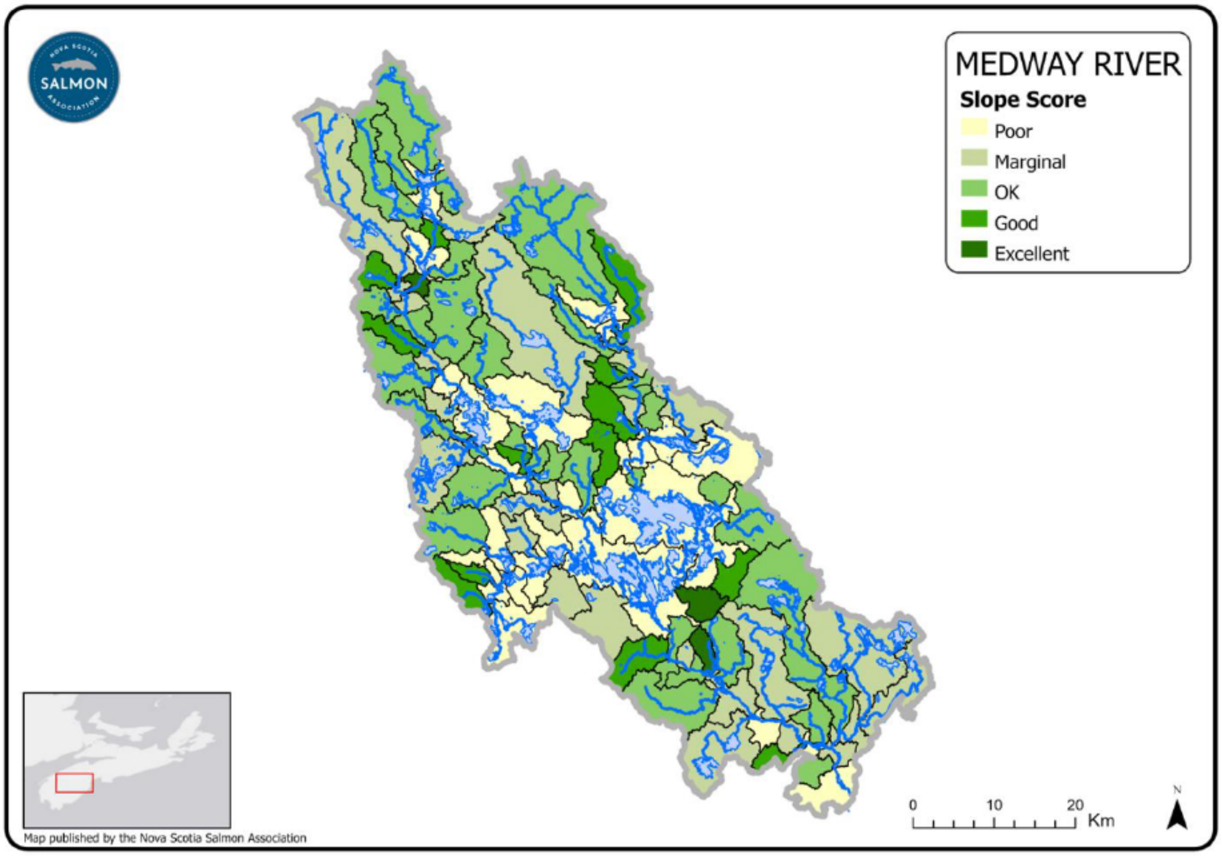

Figure 10.11- Scoring categories for slope based on the proportion of good slope for Atlantic Salmon in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada.

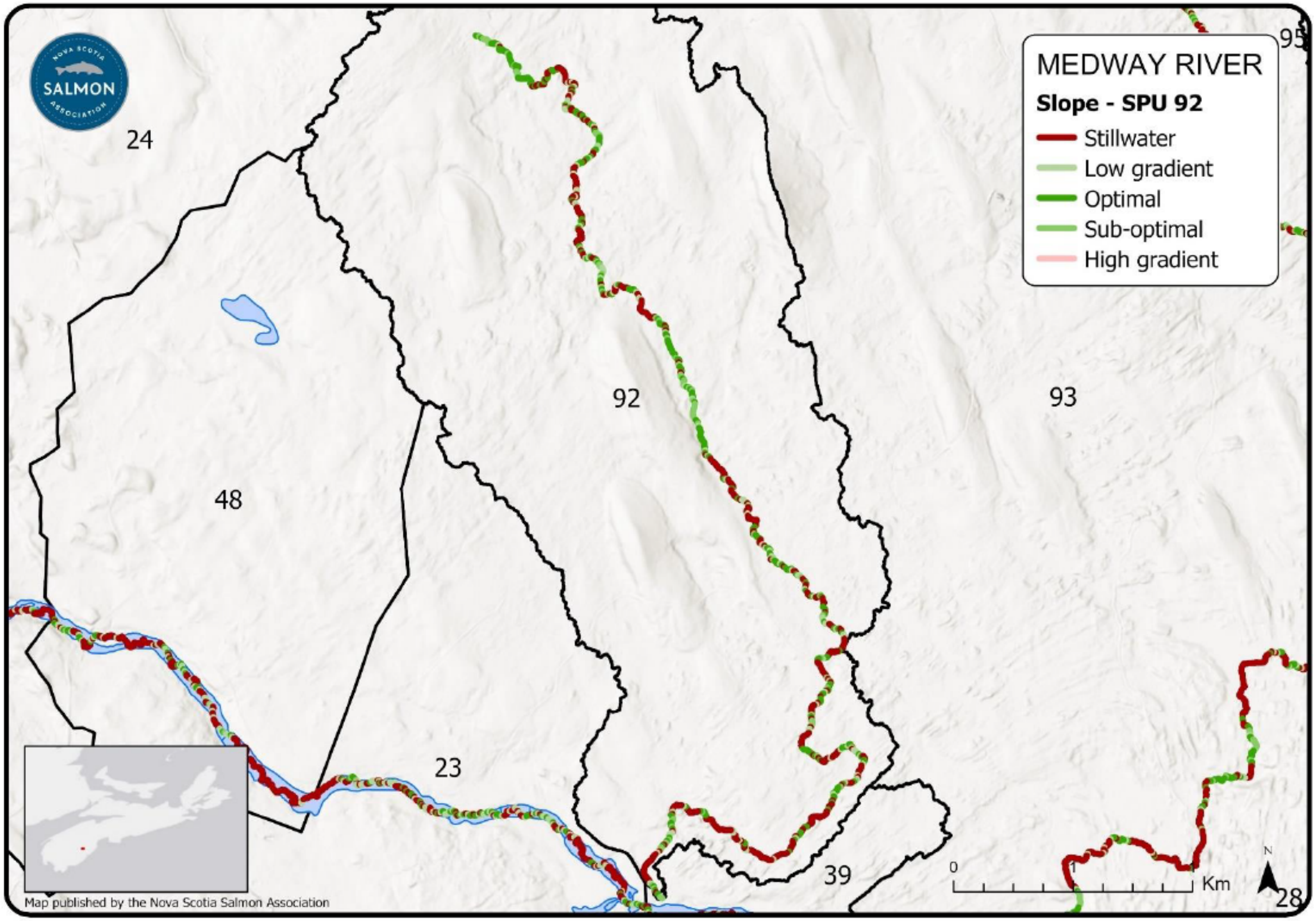

Figure 10.12 – Map of stream slope for 10m segments of spatial planning unit #92 (Buggy Hole Brook). Stream slope (%) for each classification are as follows: 'Stillwater' = 0% slope, 'Low Gradient' = 0.01 – 0.49% slope, Optimal = 0.50 – 2.99% slope, Sub-Optimal = 3.00 – 25.00% slope, High gradient = >25.00% slope.

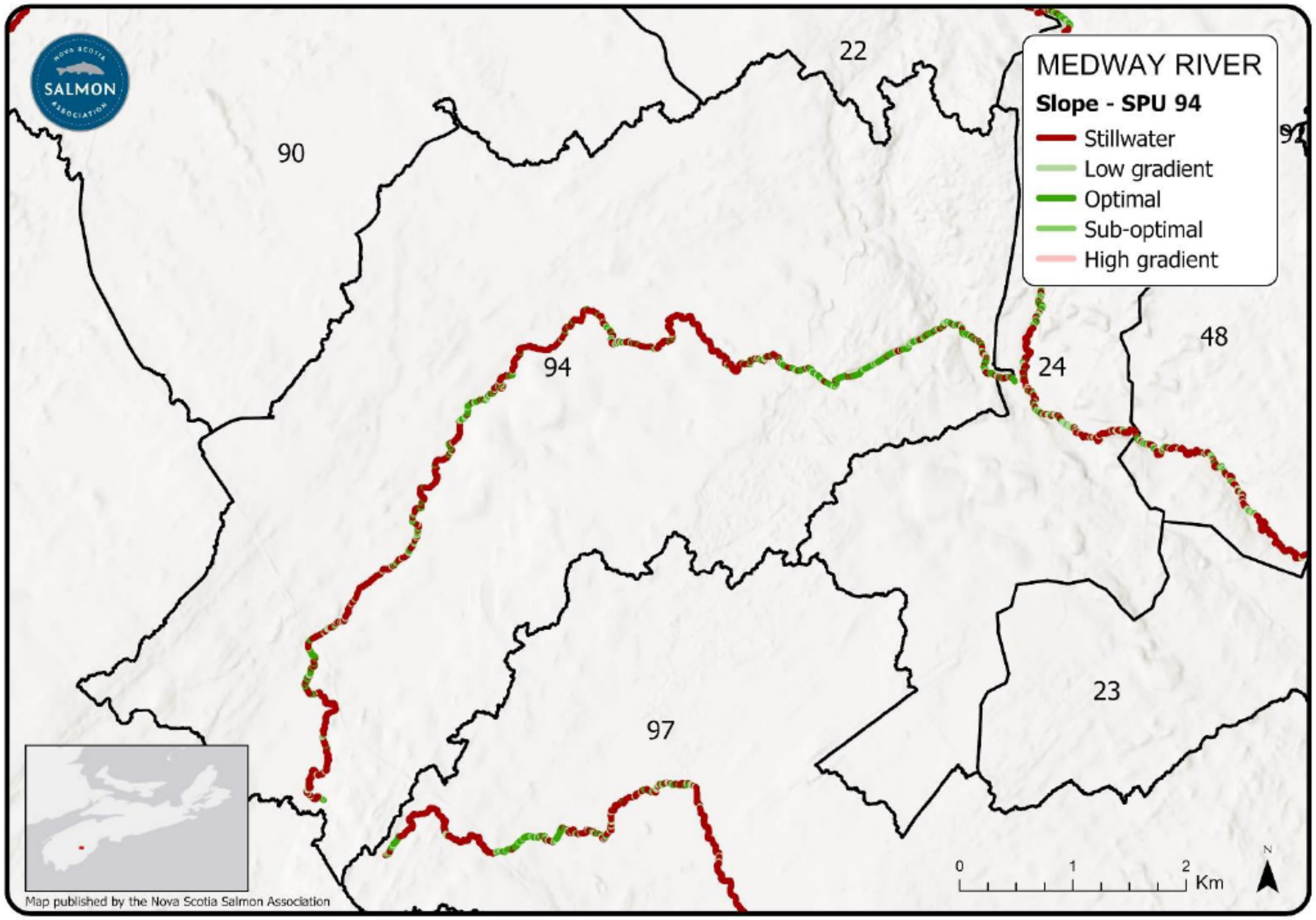

Figure 10.13 – Map of stream slope for 10m segments of spatial planning unit #94 (Fifteen Mile Brook). Stream slope (%) for each classification are as follows: 'Stillwater' = 0% slope, 'Low Gradient' = 0.01 – 0.49% slope, Optimal = 0.50 – 2.99% slope, Sub-Optimal = 3.00 – 25.00% slope, High gradient = >25.00% slope.

Riparian zone assessment

The riparian zone encompasses a 30m wide strip on both sides of the river and the following riparian score represents the proportion of riparian zone area covered with vegetation which is > 2m height. We assessed riparian scores throughout the entire Medway, however the results presented here and used in the scoring represent only fluvial (stream and river) habitat and do not represent lotic (lake and pond) habitat. Justification for this is largely related to the differing expected impact that riparian zone vegetation has on streams vs. lakes. For example, in streams, riparian cover contributes to shading which can regulate water temperature however in lakes, the area covered by riparian vegetation is small relative to the surface area of the water and therefore it's influence on temperature is considerably less.

In the Medway River, the average riparian forest cover throughout the entire watershed is 65.2% +/- 33.9 (mean +/- sd). Within any given SPU, riparian forest cover varies from 1% to 88% and the average within SPU mean is 56%. Among the SPUs, only 6/105 were ranked as "excellent" riparian forest cover score (forest cover > 75%), 46/105 ranked as "good" (forest cover > 50% < 75%), 22/105 ranked as "OK" (forest cover > 25% > 50%), 10/105 ranked as "marginal" (forest cover > 15% < 25%) and 3/105 ranked as "poor" (forest cover < 15%) (Figure 9, Table 3).

Overall, riparian cover within the Medway appears to be in good shape with much of it intact. Further, it should be noted that areas of low-gradient streams where natural wetlands (e.g. sphagnum bogs, marsh) dominate the riparian zone, this LiDAR approach would score those areas as poor due vegetation naturally being <2m height. These habitats are part of the natural landscape there this estimate is likely conservative, and the overall 'intact' riparian areas is likely higher.

Table 10.5 Riparian forest cover in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada.

SPU ID	Riparian forest cover (%)	Scoring category	SPU ID	Riparian forest cover (%)	Scoring category	SPU ID	Riparian forest cover (%)	Scoring category
1	12	Marginal	**20**	5	Poor	**39**	45	OK
2	67	Good	**21**	15	Marginal	**40**	75	Excellent
3	33	OK	**22**	13	Marginal	**41**	13	Marginal
4	70	Good	**23**	40	OK	**42**	70	Good
5	65	Good	**24**	48	OK	**43**	22	Marginal
6	59	Good	**25**	35	OK	**44**	57	Good
7	60	Good	**26**	30	OK	**45**	35	OK
8	62	Good	**27**	29	OK	**46**	35	OK
9	36	OK	**28**	45	OK	**47**	65	Good
10	27	OK	**29**	32	OK	**48**	30	OK
11	78	Excellent	**30**	1	Poor	**49**	23	Marginal
12	8	Poor	**31**	45	OK	**50**	64	Good
13	23	Marginal	**32**	76	Excellent	**51**	72	Good
14	72	Good	**33**	37	OK	**52**	64	Good
15	55	Good	**34**	69	Good	**53**	46	OK
16	73	Good	**35**	75	Excellent	**54**	48	OK
17	74	Good	**36**	22	Marginal	**55**	75	Excellent
18	51	Good	**37**	21	Marginal	**56**	49	OK
19	40	OK	**38**	87	Excellent	**57**	84	Excellent

Table 10.5 Continued. Proportion of riparian forest cover in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada.

SPU ID	Riparian forest cover (%)	Scoring category	SPU ID	Riparian forest cover (%)	Scoring category	SPU ID	Riparian forest cover (%)	Scoring category
58	57	Good	**74**	79	Excellent	**90**	53	Good
59	79	Excellent	**75**	62	Good	**91**	40	OK
60	73	Good	**76**	31	OK	**92**	79	Excellent
61	79	Excellent	**77**	83	Excellent	**93**	76	Excellent
62	63	Good	**78**	75	Excellent	**94**	88	Excellent
63	64	Good	**79**	63	Good	**95**	57	Good
64	73	Good	**80**	68	Good	**96**	60	Good
65	74	Good	**81**	71	Good	**97**	79	Excellent
66	77	Excellent	**82**	66	Good	**98**	56	Good
67	85	Excellent	**83**	66	Good	**99**	58	Good
68	70	Good	**84**	13	Marginal	**100**	59	Good
69	52	Good	**85**	75	Excellent	**101**	71	Good
70	71	Good	**86**	67	Good	**102**	83	Excellent
71	62	Good	**87**	70	Good	**103**	61	Good
72	72	Good	**88**	85	Excellent	**104**	87	Excellent
73	77	Excellent	**89**	81	Excellent	**105**	58	Good
Watershed average							**56**	**Good**

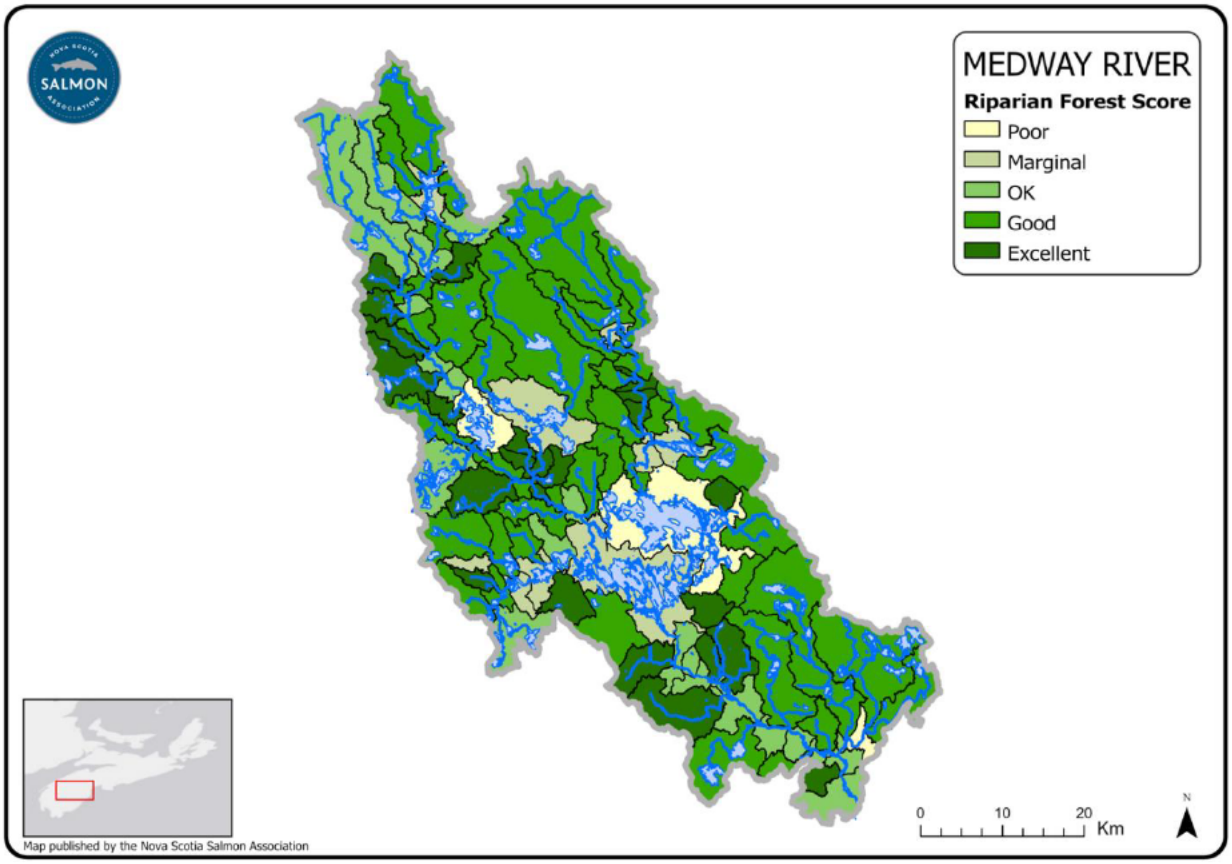

Figure 10.15 - Scoring category based on the proportion of riparian forest cover in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada.

10.2.3 Data Collection 2020-2022

Water chemistry and water temperature were sampled within the Medway River following the methods in section 6.1 at a sub-sampled number of sites that was stratified based on our initial assessment of the diversity of geology and land-use in the area as well as local knowledge of ecologically important areas. These results were then extrapolated to non-sampled sites using the modelling reported in chapter 7. Thus, the results for water chemistry and temperature represent a mixture of observed (directly sampled) and model-predicted values. For rapid reference, sampling occurred at the locations shown below.

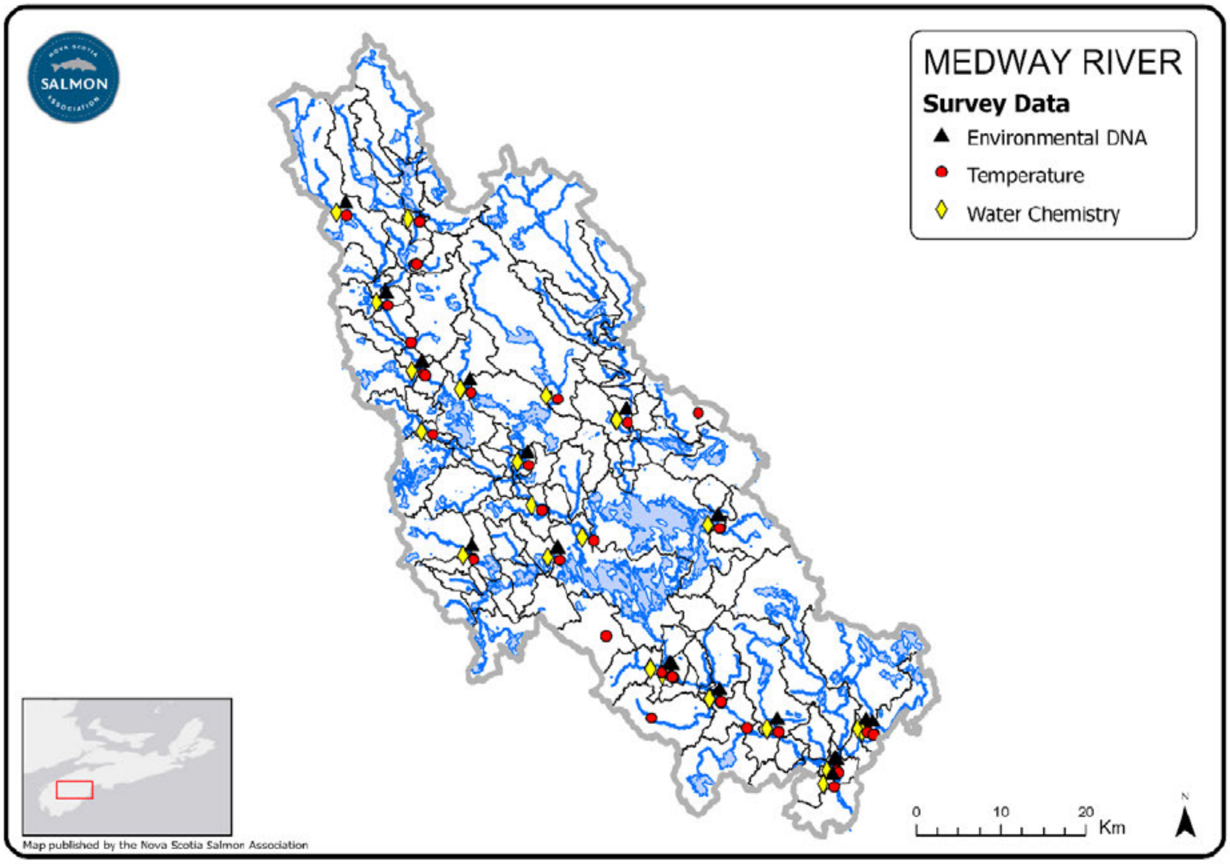

Figure 10.16 - Sampling sites for water chemistry, temperature and environmental DNA (eDNA) within the Medway River watershed.

10.2.3 Data Collection 2020-2022: Water chemistry

A total of 22 SPUs within the Medway River were sampled for water chemistry analyses on three occasions in the spring of 2021 between March 31st and May 12th. Two of these sites were further sampled monthly until November 19th 2022 (SPU 93 and 97).

Acidification status

To estimate the status of the watershed as it relates to acidification, we focused on measurements of stream pH (both field and lab-based), dissolved calcium and total alkalinity (as $CaCO_3$) at the SPU level.

Based on direct measurement of pH at the 22 sampled sites using a YSI handheld meter, the average pH was 4.36 +/- 0.42 (mean +/- sd) which was lower than the laboratory-based pH measurements of 4.98 +/- 0.37 although the field-based in-situ measurements are generally considered more reliable. Extrapolation of these data to unsampled SPUs using the machine learning model suggests that the average spring pH across the entire watershed was 4.83 +/- 0.16 and ranged from 4.10 to 5.10 (Figure 10.19, Table 10.6). Watt et al. (1983) report that the mean annual pH in the Medway River was 6.07 in the years 1954-1955 but had fallen to pH = 5.46 by 1980-1981. Later, Watt (1987) classified the Medway as having a mean annual pH of between 5.1-5.4. Watt (1987) showed a declining pH trend from the 1950s to 1980s. Our data suggest that the pH has continued to decline in the Medway River and there is yet to be any meaningful recovery from the impacts of acid rain despite reduced emissions (Watt et al. 2000) and the projected recovery from acid rain (Vet et al. 2005, Clair et al. 2011).

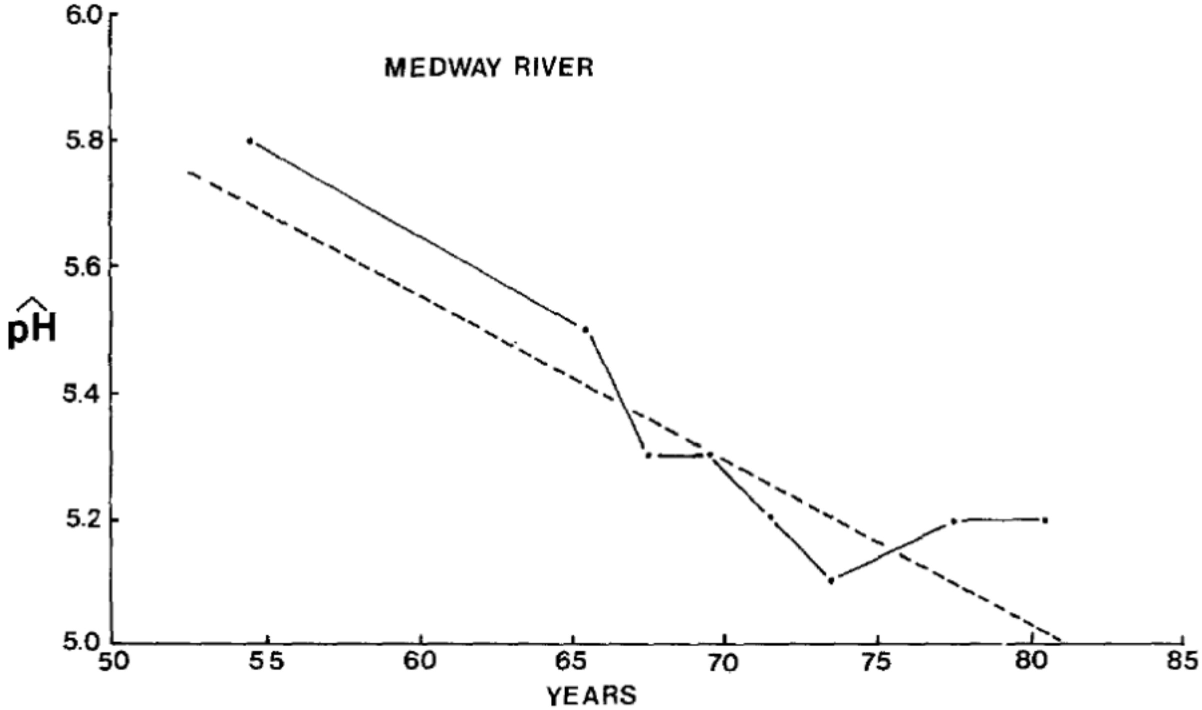

Figure 10.17 - The acidification trend in Medway River, Nova Scotia between 1954 and 1981. The dashed line represents the least squares relationship ($p < 0.01$). The pH levels have been corrected (by regression) for year-to-year variations in flow, as per Watt et al. (1983). Reproduced from Watt 1987.

The pH values reported here represent springtime values, which likely do not represent mean annual pH. The only direct data in this work with which we can compare spring vs. longer season is the two SPUs sampled from March to November where spring values were lower than the March-November average. In SPU 97 (Murray Brook), March-May pH was 4.25 +/- 0.58 compared to the March – November pH of 4.53 +/- 0.53. By contrast, SPU 93 (Dean Brook) showed a spring value of 4.77 +/- 0.54 which was similar to the March - November mean of 4.83 +/- 0.54. This is consistent with longer term datasets. For example, Watt et al. reported widespread sampling of pH in seven southern upland rivers ranging from the Tusket River to the Musquodoboit River. Watt (1987) then plotted these data, and on average mean annual pH (mean = 5.37) is ~0.1 units higher than March-May pH values (mean = 5.26, Figure 10.18).

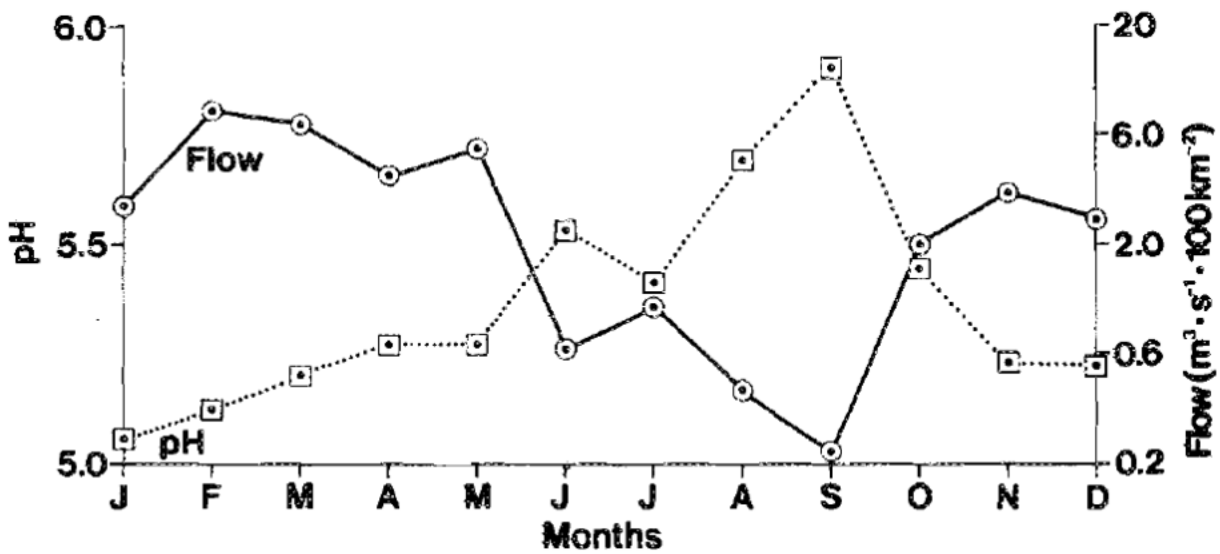

Figure 10.18 The dotted line depicts mean monthly pH for seven Southern Upland rivers between June 1980-May 1981 where sampling sites coincide with flow gauging installations. The bold line is the mean (normalized mean daily) river discharge rates. The least squares equation is pH = 5.508 - 0.459 log flow (r^2 = 0.834, P < 0.01). From Watt et al. 1983.

Laboratory-measured dissolved calcium at the 22 sampled sites was 1.08 mg/l +/- 0.33 which was slightly lower than the model-extrapolated estimate of 1.24 mg/l +/- 0.36 across all SPUs and ranged from 0.51 to 2.74 mg/l.

Laboratory-measured total alkalinity (as $CaCO_3$) at the 22 sampled sites was 2.13 mg/l +/- 0.80 which was slightly lower than the model-extrapolated estimate of 2.45 mg/l +/- 0.37 across all SPUs and ranged from 0.72 to 3.28 mg/l (Table 10.6).

The scoring category for pH ranked 26 SPUs as "poor" (pH < 4.79) and the remaining 79 SPUs as "marginal" (pH > 4.80 < 5.29) (Figure 11). For Calcium, 104 SPUs were scored as "poor" (Ca > 0.00 < 0.99 mg/l) and only one as "marginal" (Ca > 1.00 < 1.99 mg/l) (Figure 12). For alkalinity 68 SPUs were ranked as "poor" (alkalinity < 2.00 mg/l) and 37 as "marginal" (alkalinity > 2.1 to 4.9 mg/l) (Figure 13).

These calcium, magnesium and alkalinity values are expected considering the low pH values noted above and a consistent with waters sufferings from freshwater acidification. The low alkalinity suggests that the waters, also exhibiting low ionic strength (conductivity typically < 40 µS/cm, Appendix X), are poorly buffered and thus prone to rapid change in pH with relatively minor additions of acid or base.

Acid rain also mobilizes aluminum in soils, leading to increased total aluminum concentrations in rivers and streams (Sterling et al. 2020). Furthermore, under acidified conditions this aluminum shifts to the inorganic, monomeric form which is highly toxic to fish and can lead to direct mortality, particularly for anadromous fish such as salmon (McCormick et al., 2009; Staurnes et al., 1996).

Spring inorganic Aluminum levels in the Medway river were 15.1 +/- 17.8 µg/l measured three times at 22 sites. Two additional sites were measured monthly from March until November (PLU#93, Dean Brook and PLU#97, Murray Brook) where average inorganic aluminum was 19.4 µg/l and 14.3 µg/l, respectively across the year. Inorganic aluminum concentrations of 15 µg/l are not as high as seen elsewhere in Nova Scotia (Sterling et al. 2020), however it does exceed guidelines for healthy aquatic ecosystems (Howells 1990) and in the range noted to induce impairment and mortality in migrating Atlantic Salmon (McCormick et al., 2009; Staurnes et al., 1996). We were not able to fit a machine learning model to the aluminum data that provided a strong statistical ability to extrapolate the measured aluminum throughout the watershed, therefore our knowledge about aluminum is restricted to direct measurement.
Put in the context of the impacts on freshwater ecology, these pH, calcium, magnesium and alkalinity values represent conditions that would severely impact Atlantic Salmon survival and the productivity of the system in general. The two most sensitive life stages for Atlantic Salmon are thought to be just after hatching from egg while the yolk-sack is still attached (alevin) and again as the salmon undergo smoltification (Lacroix et al. 1985, Farmer et a. 1989, Farmer 2000).

Much of the preeminent research on the impacts of acidification on Atlantic Salmon has occurred within the Medway River. For example, Lacroix et al. (1985) held salmon fry in a flow-through system of tanks located in the Westfield River (SPU#38) which at the time had a mean pH = 5.0. Some tanks were treated with limestone to increase pH to 6.1 and increase calcium. Cumulative mortality of fry was 70% at pH 5.0 after 30 days in the ambient Westfield River water, whereas only 4% of fry died in the limed Westfield River water at pH 6.1.

Farmer (2000) summarized the results of several research projects and noted that significant mortality (19%-71%) is expected when fry are subjected to pH of ~5.0. He also summarized that mortality of smolts is low at pH of ~5.0, but increased to as much as 72-100% when pH fell to 4.6-4.7.

More recently, research into the sublethal effects of low pH and elevated aluminum has shown that even those smolts surviving long enough to leave their natal rivers are likely to experience increased mortality as they transition to the ocean (e.g., Staurnes et al. 1995). For example, Kroglund et al. (2007) reported a 20% to 50% reduction in marine return rate (e.g., the number of adults that return to the river as a mature adult per 1000 smolts going to sea) when exposed to only moderately acidic conditions of pH = 5.8 and inorganic aluminum concentrations of 5–15 µg/L. This is striking considering that the main Medway river averages ~0.8 pH units lower than this value during the spring period and average inorganic aluminum concentrations represents the high end of the range used by Kroglund et al.

At the level of the Atlantic Salmon population within the river, Amiro (2000) used the Atlantic Salmon Regional Acidification Model (ASRAM), developed by Korman et al. (1994), to model the stage-specific survival and population viability of Atlantic Salmon in the Medway River. He assumed an estimated average October – April stream pH of 5.30 (in 1986) and an average marine return rate of 5% but did not consider aluminum concentrations. Under these conservative conditions, Atlantic Salmon were projected to become extirpated without acid rain mitigation.

The productivity and health of the Medway River is undoubtedly greatly reduced by the ongoing legacy impacts of acid rain. Atlantic Salmon are likely to be directly affected via physiological stress and mortality. Many species, including salmon, American Eel and most probably Brook Floaters are also likely impacted by indirect impacts of reduced overall abundance of prey (invertebrates) and the diversity and abundance of other fish species.

Table 10.6- Average of pH, Calcium (mg/l) and Alkalinity (mg/l as $CaCO_3$) in the 105 spatial planning units within the Medway River watershed. "Data status" indicates whether the data was collected in field = observation (Obs.) or a prediction (Pred.) obtained through machine learning modeling.

SPU ID	Calcium	Alkalinity	pH	Data status
1	1.16	2.56	4.81	Pred.
2	0.82	1.89	4.82	Obs.
3	1.14	2.5	4.76	Pred.
4	1.2	2.85	4.86	Pred.
5	1.12	2.49	4.76	Pred.
6	2.24	2.64	5.11	Pred.
7	1.22	2.94	5.1	Pred.
8	1.14	2.63	4.89	Pred.
9	1.17	2.58	4.84	Pred.
10	1.28	2.49	4.81	Pred.
11	0.51	0.72	4.12	Obs.
12	1.56	2.47	4.81	Pred.
13	0.74	1.25	4.31	Obs.
14	1.39	2.48	4.81	Pred.
15	1.08	2.35	4.75	Pred.
16	1.13	2.5	4.8	Pred.
17	0.81	1.83	4.7	Obs.
18	1.38	2.49	4.87	Pred.
19	1.16	2.49	4.83	Pred.
20	1	2.46	4.92	Obs.
21	1.19	2.57	4.86	Pred.
22	1.18	2.49	4.83	Pred.
23	1.22	2.47	4.92	Pred.
24	1.43	2.49	4.89	Pred.
25	1.39	2.49	4.9	Pred.
26	1.05	2.28	4.96	Obs.
27	1.2	2.41	4.94	Pred.
28	1.42	2.9	4.95	Obs.
29	1.19	2.49	4.92	Pred.
30	1.38	2.35	4.93	Pred.
31	2.74	2.49	4.89	Pred.
32	1.14	2.62	4.95	Pred.
33	0.82	1.58	4.5	Obs.
34	1.13	2.63	4.87	Pred.
35	1.4	2.49	4.83	Pred.

Table 10.6 - Continued. Average of pH, Calcium (mg/l) and Alkalinity (mg/l as $CaCO_3$) in the 105 spatial planning units within the Medway River watershed. "Data status" indicates whether the data was collected in field = observation (Obs.) or a prediction (Pred.) obtained through machine learning modeling.

SPU ID	Calcium	Alkalinity	pH	Data status
36	1.12	2.63	4.87	Pred.
37	1.44	3.11	5.04	Pred.
38	0.73	1.7	4.51	Obs.
39	1.32	2.48	4.92	Pred.
40	1.39	2.49	4.81	Pred.
41	1.66	2.65	4.93	Pred.
42	1.16	2.5	4.81	Pred.
43	1.23	2.49	4.82	Pred.
44	1.13	2.49	4.82	Pred.
45	1.03	2.17	4.77	Obs.
46	1.19	2.49	4.92	Pred.
47	1.06	2.48	4.88	Pred.
48	0.97	2.22	4.95	Obs.
49	1.23	2.73	5.07	Pred.
50	1.08	2.49	4.82	Pred.
51	1.16	2.48	4.82	Pred.
52	1.12	2.49	4.78	Pred.
53	1.15	2.65	4.76	Pred.
54	2.34	2.5	4.96	Pred.
55	2.24	2.85	4.87	Pred.
56	0.72	1.24	4.25	Obs.
57	1.38	3.28	4.94	Pred.
58	1.14	2.62	4.84	Pred.
59	1.43	2.61	5.14	Pred.
60	1.1	2.64	5.01	Pred.
61	1.13	2.44	4.7	Pred.
62	1.07	2.64	4.76	Pred.
63	1.07	2.47	4.76	Pred.
64	1.17	2.55	4.82	Pred.
65	2.34	2.58	4.82	Pred.
66	0.89	2.29	4.81	Obs.
67	1.13	2.87	4.81	Pred.
68	0.68	1.04	4.31	Obs.
69	1.06	2.64	4.94	Pred.
70	1.12	1.98	4.65	Obs.

Table 10.6 - Continued. Average of pH, Calcium (mg/l) and Alkalinity (mg/l as $CaCO_3$) in the 105 spatial planning units within the Medway River watershed. "Data status" indicates whether the data was collected in field = observation (Obs.) or a prediction (Pred.) obtained through machine learning modeling.

SPU ID	Calcium	Alkalinity	pH	Data status
71	1.36	2.48	4.81	Pred.
72	1.32	2.65	5	Pred.
73	1.09	2.35	4.78	Pred.
74	1.12	2.49	4.88	Pred.
75	1.09	2.53	4.82	Pred.
76	1.32	2.49	4.81	Pred.
77	1.43	2.63	4.94	Pred.
78	1.14	2.49	4.82	Pred.
79	1.14	2.49	4.83	Pred.
80	1.11	2.49	4.83	Pred.
81	0.97	2.83	4.85	Obs.
82	1.02	2.36	4.76	Obs.
83	2.34	2.48	4.81	Pred.
84	1.45	2.5	4.81	Pred.
85	1.15	2.51	4.82	Pred.
86	1.17	2.63	4.87	Pred.
87	1.15	2.41	4.8	Pred.
88	1.2	2.49	4.82	Pred.
89	1.15	2.49	4.82	Pred.
90	1.07	2.49	4.95	Pred.
91	1.51	2.49	4.82	Pred.
92	1.22	2.85	4.88	Pred.
93	1.39	2.49	4.78	Pred.
94	1.14	2.48	4.92	Pred.
95	1.11	2.57	4.69	Obs.
96	1.1	2.13	4.76	Obs.
97	1.38	2.56	4.56	Obs.
98	1.09	1.85	4.54	Obs.
99	1.16	2.48	4.92	Pred.
100	1.14	2.64	4.98	Pred.
101	1.39	2.49	4.92	Pred.
102	1.16	2.64	5.01	Obs.
103	1.22	2.48	5.02	Pred.
104	1.06	2.35	4.75	Pred.
105	2.34	2.65	4.93	Pred.
Watershed average	**1.24**	**2.45**	**4.83**	**22 observations**

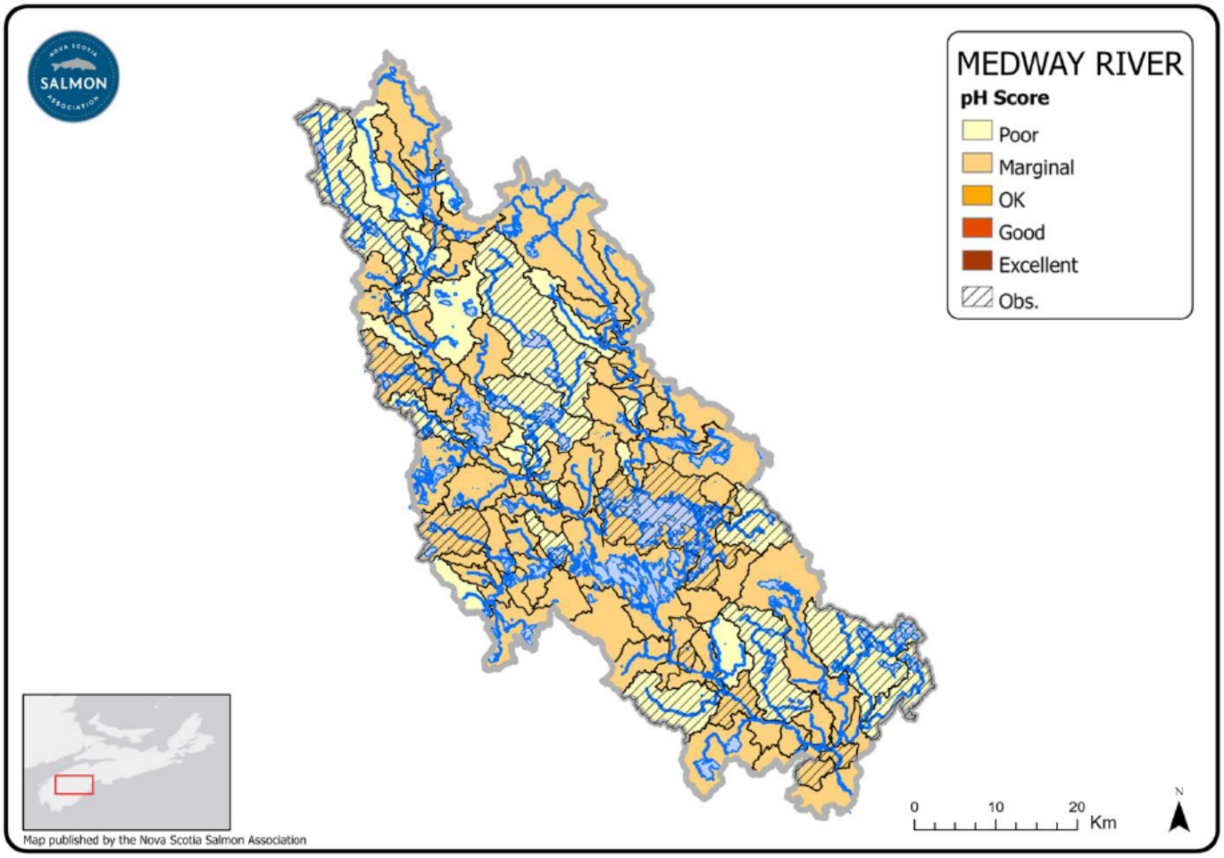

Figure 10.19 - Scoring category based on pH levels in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada. Hatching lines indicate the SPUs where the data was collected and undashed SPUs show predicted values.

The higher pH value was observed in the middle section of the watershed, while the lowest pH values were found in middle upper tributaries and near the mouth of the main channel. As expected, similar patterns were found for alkalinity and calcium once pH, calcium and alkalinity were highly correlated (Spearman rank correlation > 0.60; p-value < 0.05).

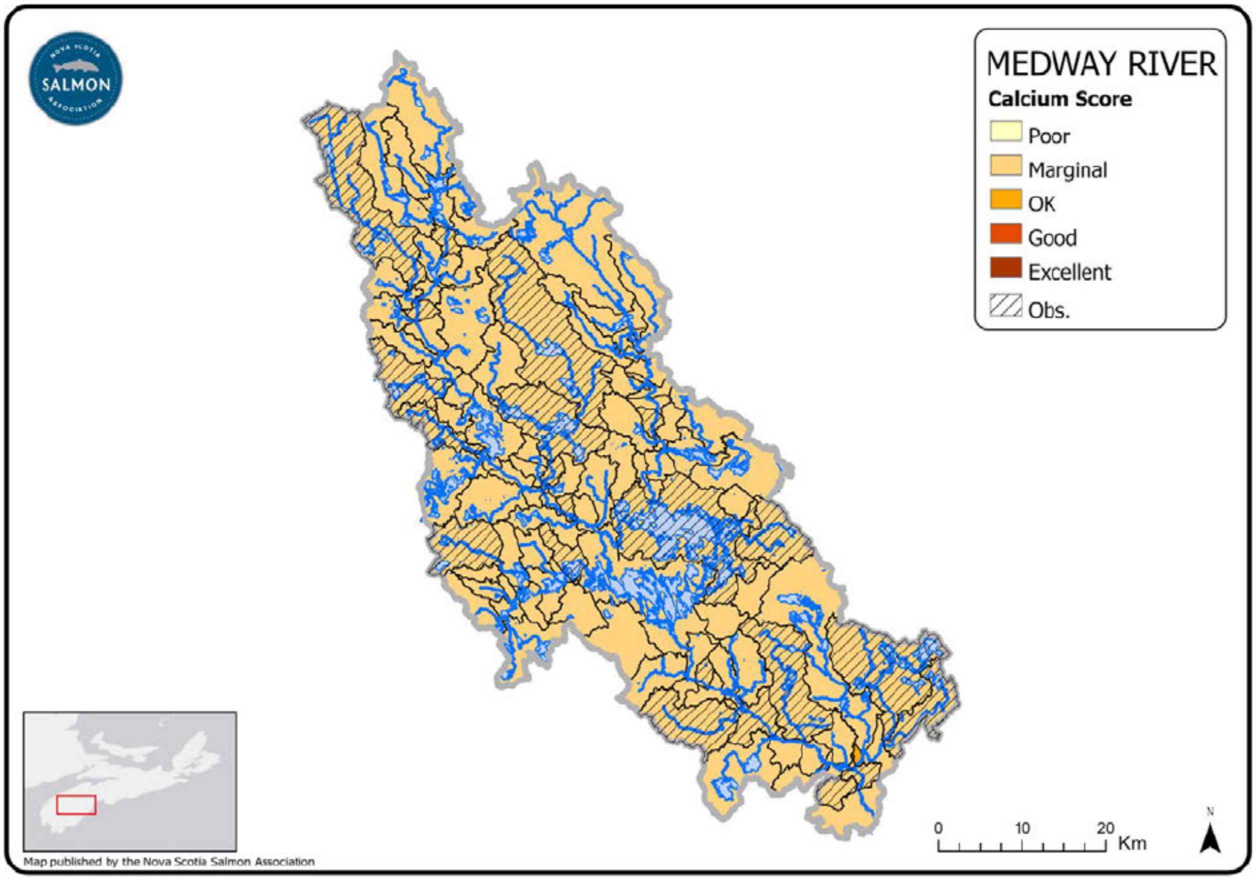

Figure 10.20 - Scoring category based on Calcium levels in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada. Hatching lines indicate the SPUs where the data was collected and undashed SPUs show predicted values.

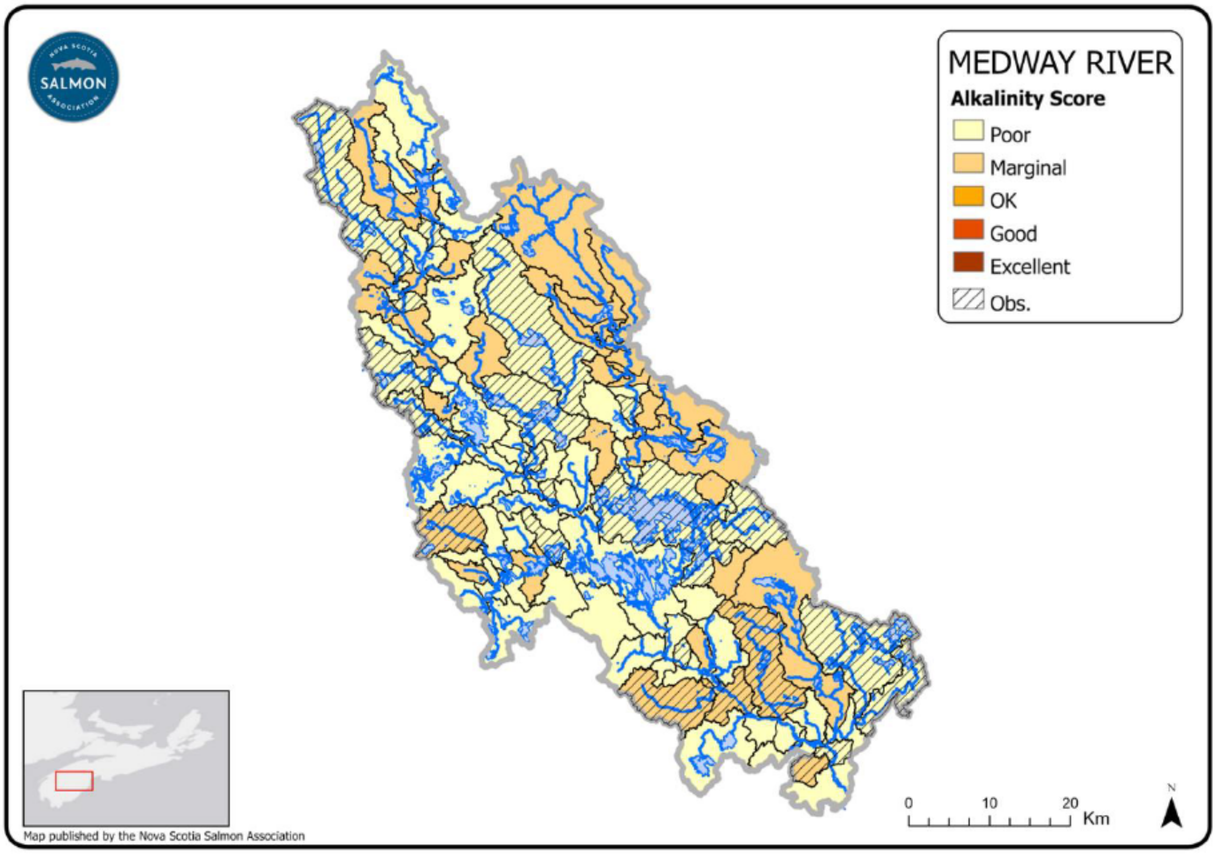

Figure 10.21 - Scoring category based on alkalinity levels in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada. Hatching lines indicate the SPUs where the data was collected and undashed SPUs show predicted values.

Productivity

We used nitrates, total dissolved solids (TDS), phosphorus, and total organic carbon (TOC) as metrics to estimate productivity at SPU level.

Based on laboratory measurement of water chemistry samples from 22 sites, the average nitrate concentration was 42.0 +/- 28.5 µg/l (mean +/- sd). Extrapolation of these data to unsampled SPUs using the machine learning model suggests that the average spring nitrate concentration across the entire watershed was 151.3 +/- 200.5 and ranged from 14.2 to 1061.0 (Table 10.7), highlighting that some variables that were important predictors of nitrate was much higher in unsampled SPUs compared to the 22 sampled SPUs. The score focused on nitrates ranked five SPUs were ranked "good" (nitrate between 500 and 1499 µg/l) and 100 SPUs as "Excellent" (nitrate > 10 < 99.9 µg/l)(Table 10.7).

Laboratory measurements of Phosphorus at the 22 sampled SPUs was 9.4 +/- 6.6 µg/l. Extrapolation of these data to unsampled SPUs using the machine learning model showed average spring phosphorus concentration across the entire watershed was 14.1 +/- 8.9 and ranged from 4.3 to 53.3 (Table 10.7). Phosphorus levels were mostly very good across the watershed with 29 SPUs ranked as "excellent" (15 to 29.9 µg/l), 73 SPUs as "good" (5.0 to 14.9 µg/l) and 3 SPUs as "OK" where one was ultra unproductive at <5 µg/l (SPU#20, sampled at Wildcat River) and the other two were based on model predictions and were just over 50 µg/l (Table 10.7).

Laboratory measurements of TDS at the 22 sampled SPUs was 23.1 +/- 4.6 mg/l. Extrapolation of these data to unsampled SPUs using the machine learning model showed average spring TDS concentration across the entire watershed was 22.8 +/- 3.0 mg/l and ranged from 16.6 to 34.3 (Table 10.7). TDS levels were mostly ranked as "OK" with 85 SPUs between 20 and 29.9 mg/l, 18 SPUs ranked as "marginal" (10 to 19.9 mg/l) and only two SPUs as "good" (30 < 39.9 mg/l) (Figure 10.23) In this case, we consider that TDS represent ions in the water which are essential to ecosystem productivity and related to the productivity of freshwater, particularly lakes (Ryder et al. 1974). Such ions are usually the cations calcium, magnesium, sodium and potassium and the anions carbonate, bicarbonate, chloride, sulphate and occasionally nitrate which is usually indicative of agricultural inputs or human wastewater effluent. These ions can become detrimental detrimental to aquatic health when TDS become elevated, however guidelines are usually >500 mg/l which is rarely observed in the Southern Uplands.

Laboratory measurements of TOC at the 22 sampled SPUs was 10.2 +/- 4.4 mg/l. Extrapolation of these data to unsampled SPUs using the machine learning model showed average spring TDS concentration across the entire watershed was 8.0 +/- 1.7 mg/l and ranged from 5.4 to 16.0 mg/l (Table 10.7). For TOC, 97 SPUs were ranked as "OK" (5 to 9.9 mg/l), 7 SPUs were "marginal" (10 to 14.9 mg/l), and one SPU as "poor" (TOC > 15 mg/l) (Figure 10.24)

Table 10.7 - Average Nitrates (µg/l), total dissolved solids (TDS, mg/l), total organic carbon (TOC, mg/l) and phosphorus (µg/l) in each of the 105 spatial planning units within the Medway River watershed. Data status indicates whether the data was collected in field = observation (Obs.) or a prediction (Pred.) obtained through machine learning models.

SPU ID	Nitrates	TDS	TOC	Phosphorus	Data status
1	451.8	20.9	7.5	10.1	Pred.
2	30.1	19.7	7.7	6.8	Obs.
3	61.4	23.8	5.7	10.9	Pred.
4	95.0	25.1	5.5	10.9	Pred.
5	97.8	23.7	7.9	18.5	Pred.
6	131.3	29.8	9.1	9.5	Pred.
7	97.8	20.7	6.6	32.4	Pred.
8	114.6	20.9	8.2	11.6	Pred.
9	85.2	20.8	5.4	10.2	Pred.
10	110.3	19.6	9.2	11.5	Pred.
11	14.9	19.8	9.7	7.1	Obs.
12	165.6	22.7	7.9	10.3	Pred.
13	45.6	20.5	11.0	7.3	Obs.
14	85.2	19.5	7.0	8.6	Pred.
15	87.9	24.8	7.6	8.3	Pred.
16	84.6	20.3	6.3	9.3	Pred.
17	21.2	20.3	7.8	6.1	Obs.
18	103.3	19.2	5.9	8.6	Pred.
19	102.7	20.9	5.4	9.2	Pred.
20	74.8	20.3	6.3	4.3	Obs.
21	179.3	25.4	8.0	10.7	Pred.
22	274.6	21.0	7.6	9.4	Pred.
23	92.9	19.6	12.0	24.7	Pred.
24	51.8	19.8	11.3	16.3	Pred.
25	85.2	19.4	8.8	17.3	Pred.
26	38.9	21.3	7.3	8.4	Obs.
27	105.1	21.4	9.6	18.5	Pred.
28	21.8	22.4	15.0	13.8	Obs.
29	77.9	21.3	8.9	14.5	Pred.
30	110.3	25.4	9.1	21.9	Pred.
31	48.7	29.0	10.6	16.6	Pred.
32	143.8	26.0	7.9	12.8	Pred.
33	29.9	20.3	8.6	8.1	Obs.
34	152.4	25.6	8.1	8.6	Pred.
35	93.5	23.9	5.8	12.8	Pred.

Table 10.7 - Continued. Average Nitrates (µg/l), total dissolved solids (TDS, mg/l), total organic carbon (TOC, mg/l) and phosphorus (µg/l) in each of the 105 spatial planning units within the Medway River watershed. Data status indicates whether the data was collected in field = observation (Obs.) or a prediction (Pred.) obtained through machine learning models.

SPU ID	Nitrates	TDS	TOC	Phosphorus	Data status
36	114.1	20.5	9.0	12.7	Pred.
37	110.9	22.7	8.9	9.6	Pred.
38	33.8	19.1	8.0	5.1	Obs.
39	84.5	19.5	10.1	17.7	Pred.
40	83.2	19.3	6.5	9.7	Pred.
41	111.1	26.5	9.0	8.3	Pred.
42	87.7	25.2	6.7	9.8	Pred.
43	59.4	25.7	6.8	10.4	Pred.
44	91.0	25.6	7.8	9.5	Pred.
45	21.9	21.6	8.2	7.9	Obs.
46	90.2	21.7	8.8	19.7	Pred.
47	103.3	23.0	6.2	9.5	Pred.
48	55.4	21.1	7.2	5.9	Obs.
49	258.1	21.6	8.8	12.3	Pred.
50	172.6	16.6	5.5	8.7	Pred.
51	80.2	21.6	6.3	11.1	Pred.
52	84.5	20.2	6.0	8.6	Pred.
53	98.6	19.9	7.2	8.7	Pred.
54	265.9	25.9	8.2	9.9	Pred.
55	156.7	24.2	7.4	18.8	Pred.
56	52.1	22.1	9.1	7.6	Obs.
57	95.2	19.3	8.0	18.7	Pred.
58	69.6	24.5	7.9	21.4	Pred.
59	94.9	23.9	7.0	21.1	Pred.
60	82.5	18.6	7.6	9.6	Pred.
61	388.6	22.3	7.5	16.2	Pred.
62	64.9	23.1	7.4	18.4	Pred.
63	143.6	24.9	8.1	11.9	Pred.
64	1060.6	23.5	7.1	13.0	Pred.
65	232.5	25.9	9.3	9.9	Pred.
66	31.9	19.4	7.1	7.2	Obs.
67	96.2	20.8	5.6	12.7	Pred.
68	21.3	20.6	10.0	6.7	Obs.
69	524.0	23.6	7.1	8.6	Pred.
70	28.3	34.1	10.4	9.5	Obs.

Table 10.7 - Continued. Average Nitrates (µg/l), total dissolved solids (TDS, mg/l), total organic carbon (TOC, mg/l) and phosphorus (µg/l) in each of the 105 spatial planning units within the Medway River watershed. Data status indicates whether the data was collected in field = observation (Obs.) or a prediction (Pred.) obtained through machine learning models.

SPU ID	Nitrates	TDS	TOC	Phosphorus	Data status
71	97.5	21.8	8.2	11.1	Pred.
72	52.6	23.9	8.0	13.1	Pred.
73	218.9	25.3	6.2	27.0	Pred.
74	83.3	23.5	6.3	8.9	Pred.
75	157.5	25.1	6.5	24.8	Pred.
76	170.2	21.1	8.3	15.7	Pred.
77	388.6	23.8	6.0	29.9	Pred.
78	84.1	25.9	8.5	8.9	Pred.
79	141.7	22.9	5.9	23.4	Pred.
80	117.6	23.5	7.8	10.1	Pred.
81	14.2	22.3	9.1	10.0	Obs.
82	25.8	25.8	7.3	21.7	Obs.
83	1012.6	25.9	8.0	9.9	Pred.
84	92.9	25.4	5.7	10.2	Pred.
85	96.2	21.4	6.7	18.5	Pred.
86	1060.6	23.2	8.3	12.4	Pred.
87	151.0	25.8	6.9	11.0	Pred.
88	137.3	22.3	7.9	10.3	Pred.
89	284.9	24.2	7.1	53.3	Pred.
90	110.3	24.5	8.6	20.1	Pred.
91	119.4	23.2	9.0	12.8	Pred.
92	266.4	19.3	9.9	50.2	Pred.
93	93.5	25.3	7.4	18.0	Pred.
94	1057.7	23.3	8.4	38.7	Pred.
95	22.7	19.0	8.2	5.1	Obs.
96	27.1	24.3	8.3	6.7	Obs.
97	37.0	28.4	16.0	13.2	Obs.
98	25.9	34.3	9.8	7.5	Obs.
99	226.2	22.4	7.7	28.2	Pred.
100	92.2	23.7	8.6	12.2	Pred.
101	158.5	21.7	9.6	49.9	Pred.
102	15.9	21.3	9.9	13.6	Obs.
103	120.2	22.3	8.0	11.9	Pred.
104	157.3	23.1	6.0	23.4	Pred.
105	257.0	25.9	9.6	9.9	Pred.
Watershed mean	**151.3**	**22.8**	**8.0**	**14.1**	**22 observations**

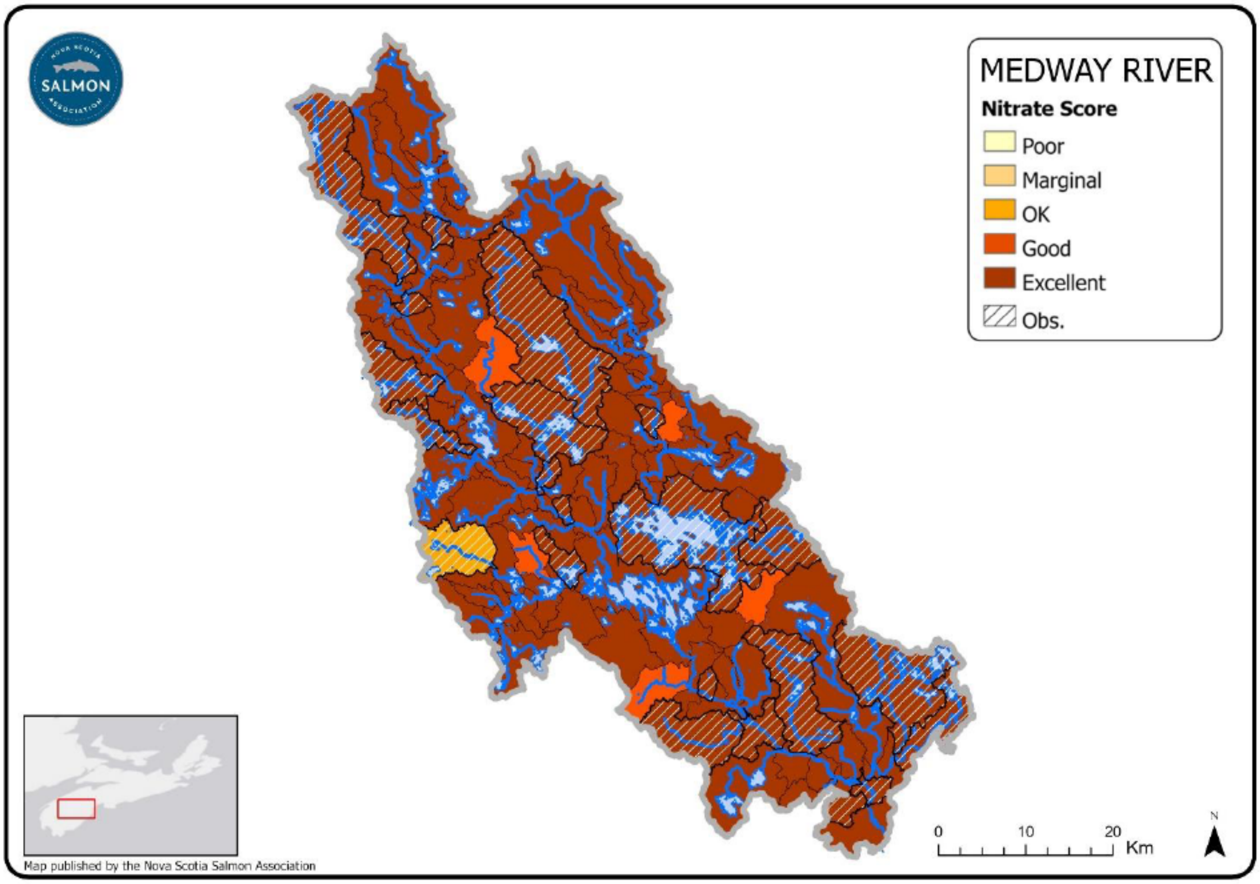

Figure 10.22 Scoring category based on nitrate levels in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada. Hatching lines indicate the SPUs where the data was collected and undashed SPUs show predicted values.

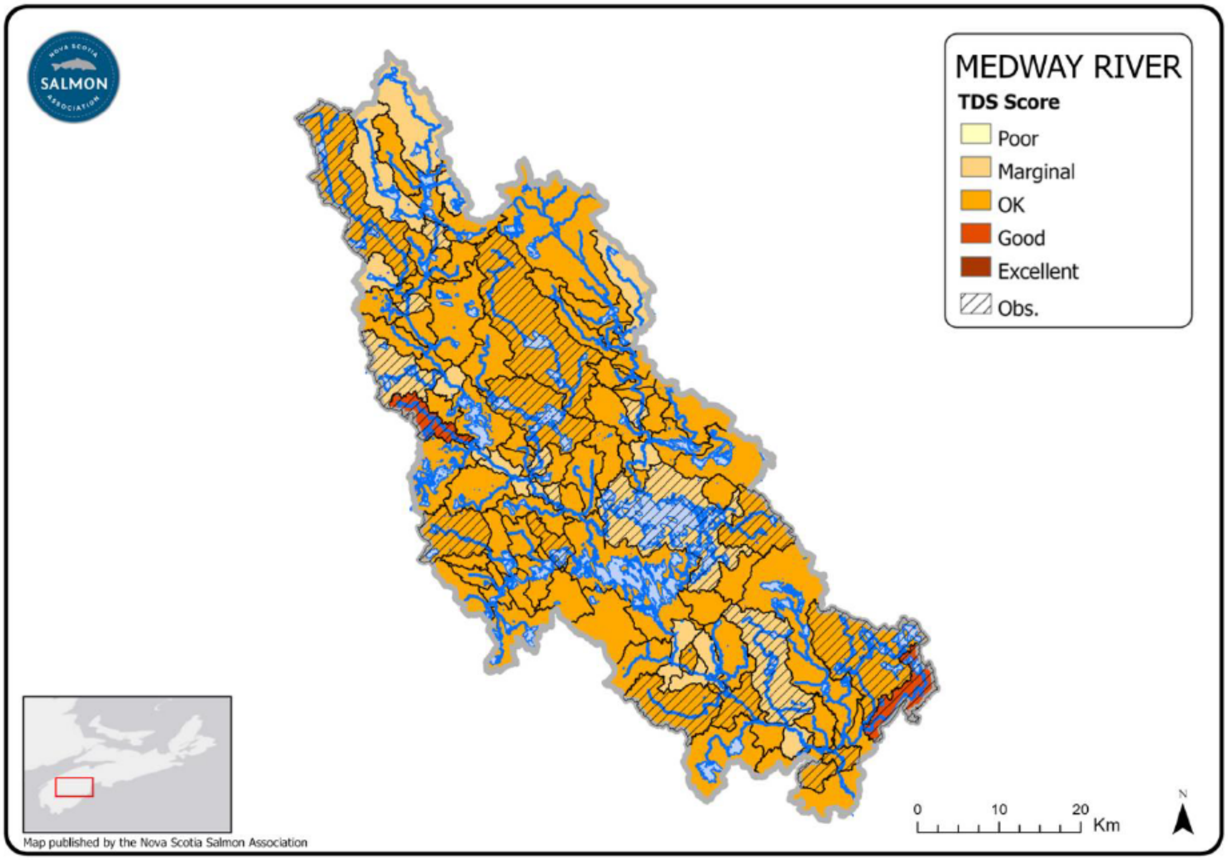

Figure 10.23. Scoring category based on Total Dissolved Solids - TDS in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada. Hatching lines indicate the SPUs where the data was collected and undashed SPUs show predicted values.

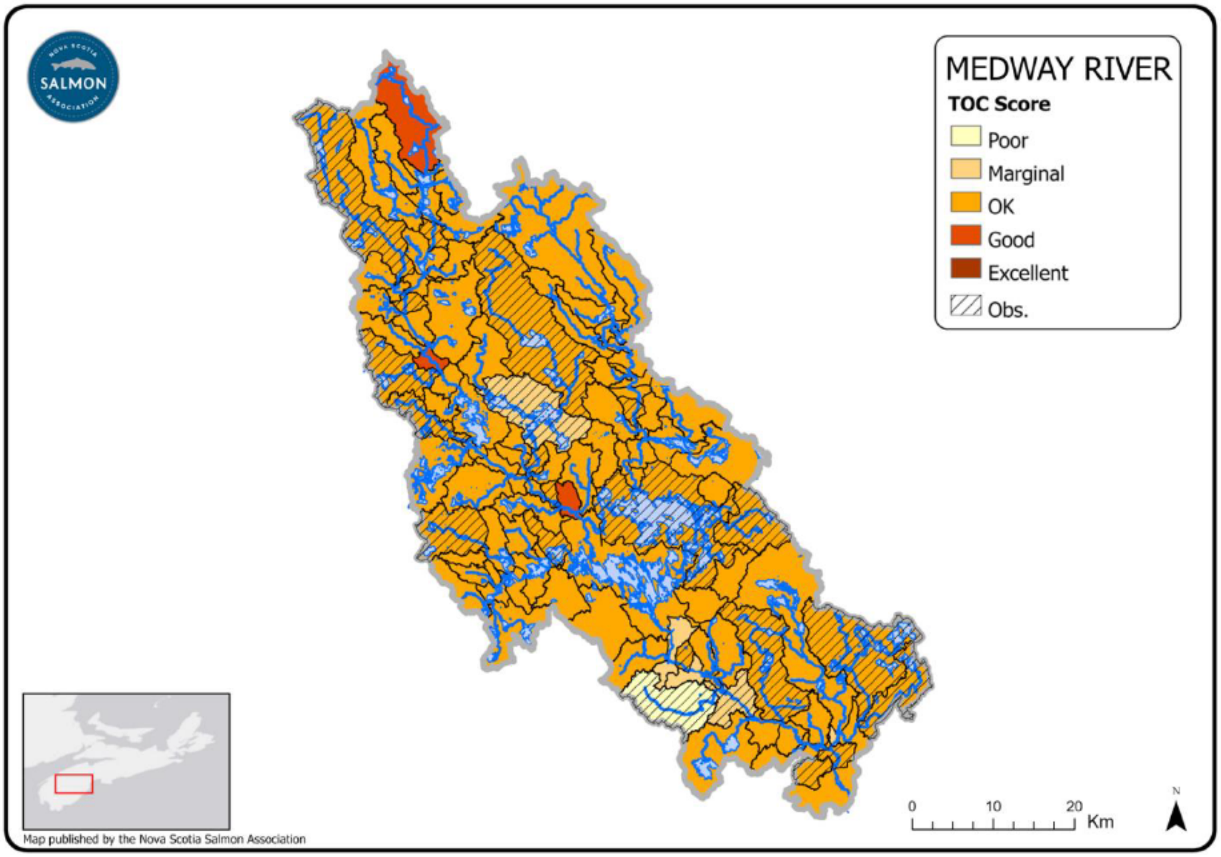

Figure 10.24 Scoring categories based on the average Total Organic Carbon - TOC in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada. Hatching lines indicate the SPUs where the data was collected and undashed SPUs show predicted values.

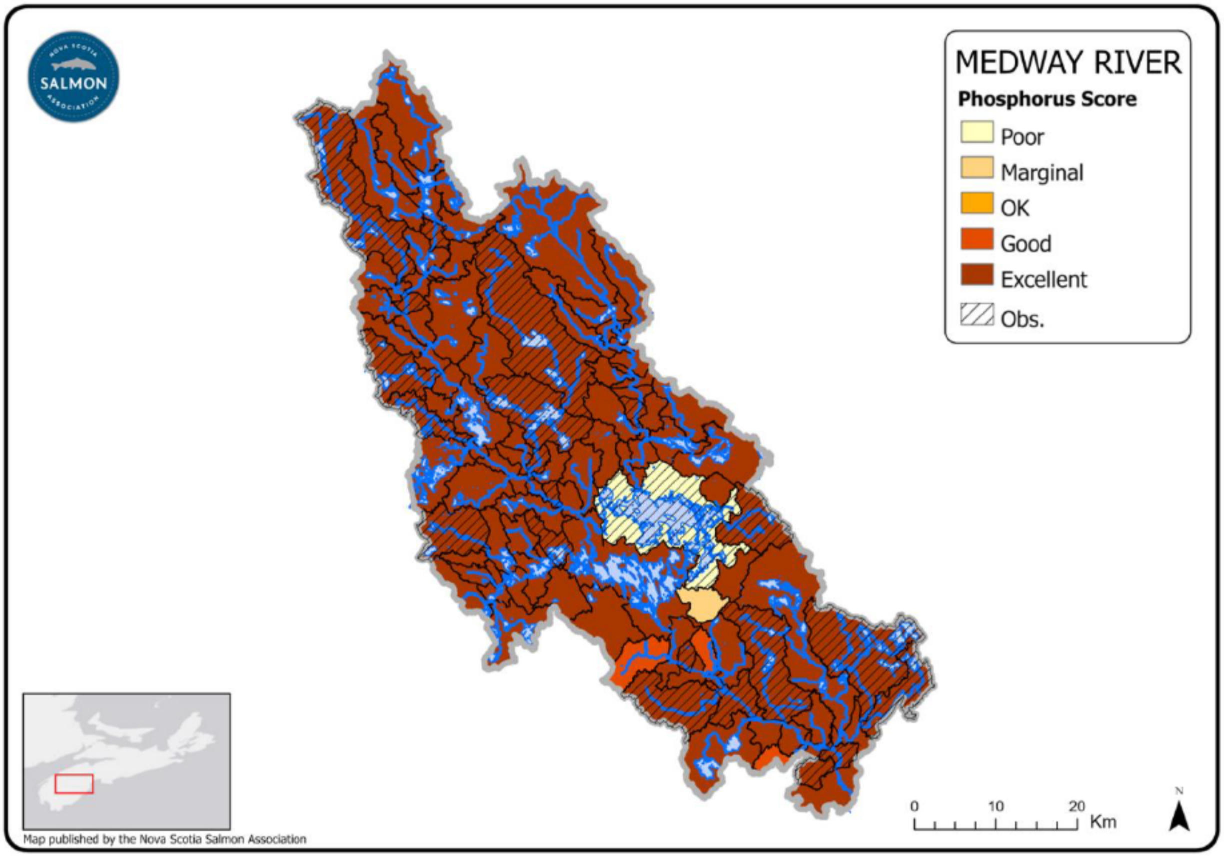

Figure 10.25 Scoring categories based on phosphorus levels in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada. Hatching lines indicate the SPUs where the data was collected and undashed SPUs show predicted values.

High levels of nitrates were found along the main channel and the middle lower section where lakes there is a high concentration of lakes. A single upper tributary presented nitrates concentration above 500 mg/l. The phosphorus levels were mostly low across the watershed, while TOC levels were predominantly intermediate across the watershed with the highest TOC levels recorded in the central portion of the watershed.

10.2.4 Data Collection 2020-2022: Water temperature

Stationary loggers and mobile loggers were used to monitor water temperature and provide data to develop temperature profiles of both sub watersheds. Temperature was recoded at 15-minute intervals between June 12 and November 17th, 2020 at 13 sites. In 2021, temperature data were collected between June 1 and September 2021 at 26 sites. Only the 2021 data we included in the modelling to extrapolate to the entire watershed. Using these 'summer period' water temperature data, we calculated three metrics to describe temperature for each SPU: 1 – average temperature, 2 – number of days with maximum temperature above 20ºC (days/MAX 20ºC), and 3 - number of days with minimum temperature above 20ºC (days/MIN 20º C). For more information, please see the methods section in chapter 5.

Across all SPUs, the average June 1st to September 30th 2021 temperature in the Medway River watershed was 20.4ºC, while the average number of days with maximum and minimum temperature above 20º C was 0.69 and 0.39 days, respectively (Table 7). Among the 105 SPUs that compose the watershed, the average temperature ranged from 17.1ºC to 22ºC, days/MAX 20ºC varied from 0.26 to 0.93 days, and days/MIN 20ºC from 0.04 to 0.68 days.

Based on the average temperature, 56 SPUs were ranked as "OK" (avg. Temp. > 20 < 22ºC), 29 SPUs as "good" (avg. Temp. > 18 < 20ºC), 14 SPUs as "marginal" (avg. Temp. > 22 < 24ºC), and six SPU as "poor" (avg. Temp. > 24ºC) (Figure 16). The number of days with minimum temperature above 20ºC varied from poor to excellent across the watershed with 40 SPUs ranked as "marginal" (days/MIN 20º C > 0.40 < 0.60 days), 31 SPUs as "OK" (days/MIN 20º C > 0.20 < 0.40), 21 SPUs as "poor" (days/MIN 20ºC > 0.60), 11 SPUs as "good" (days/MIN 20ºC > 0.10 < 0.20), and only two SPUs as "excellent" (days/MIN 20ºC < 0.10) (Figure 17).

In contrast, the number of days with maximum temperature above 20ºC varied was predominantly high with 83 SPUs ranked as "poor" (days/MAX 20ºC > 0.60), 17 SPUs as "marginal" (days/MAX 20ºC > 0.40 < 0.60), and five as "OK" (days/MAX 20ºC > 0.20 < 0.40) (Figure 18).

Table 10.8 – Water temperature metrics from June 1 to September 30, 2021: average temperature (° C), proportion of summer when daily maximum temperature exceeded 20° C (days w/ MAX >20° C), and the proportion of summer when daily minimum temperature exceeded 20° C (days w/ MIN >20° C) for each of the 105 spatial planning units within the Medway River watershed. Data status denotes whether the data are field observation (Obs.) or a prediction (Pred.) obtained through machine learning models.

SPU ID	Average temperature (°C)	Days w/ MIN > 20°C	Days w/ MAX > 20°C	Data status
1	21.7	0.61	0.81	Pred.
2	22.3	0.68	0.92	Obs.
3	21	0.47	0.72	Pred.
4	19.5	0.27	0.51	Pred.
5	20.4	0.36	0.64	Pred.
6	20.2	0.36	0.72	Pred.
7	19.4	0.23	0.55	Pred.
8	21.1	0.48	0.83	Pred.
9	22.2	0.7	0.89	Obs.
10	19.2	0.39	0.52	Obs.
11	21.3	0.44	0.84	Obs.
12	21.2	0.5	0.78	Pred.
13	10.9	0.09	0.42	Obs.
14	20.7	0.37	0.74	Pred.
15	21	0.48	0.79	Pred.
16	20.3	0.31	0.74	Pred.
17	22	0.63	0.92	Obs.
18	21.7	0.64	0.85	Pred.
19	22.1	0.7	0.81	Pred.
20	23	0.79	0.92	Obs.
21	21.1	0.46	0.73	Pred.
22	22.1	0.66	0.83	Pred.
23	21	0.32	0.73	Pred.
24	20.6	0.36	0.71	Pred.
25	21.1	0.45	0.66	Pred.
26	23	0.83	0.94	Obs.
27	20.5	0.35	0.73	Pred.
28	20.2	0.32	0.79	Obs.
29	20.9	0.42	0.78	Pred.
30	20.2	0.29	0.66	Pred.
31	21.1	0.42	0.74	Pred.
32	20.9	0.39	0.69	Pred.
33	22.2	0.71	0.89	Obs.

Table 10.8 – Continued. Water temperature metrics from June 1 to September 30, 2021: average temperature (° C), proportion of summer when daily maximum temperature exceeded 20° C (days w/ MAX >20° C), and the proportion of summer when daily minimum temperature exceeded 20° C (days w/ MIN >20° C) for each of the 105 spatial planning units within the Medway River watershed. Data status denotes whether the data are field observation (Obs.) or a prediction (Pred.) obtained through machine learning models.

SPU ID	Average temperature (°C)	Days w/ MIN > 20°C	Days w/ MAX > 20°C	Data status
34	20	0.3	0.65	Pred.
35	20.5	0.36	0.74	Pred.
36	21.5	0.61	0.77	Pred.
37	20.7	0.43	0.76	Pred.
38	21.9	0.77	0.93	Obs.
39	20.8	0.39	0.72	Pred.
40	20.5	0.37	0.74	Pred.
41	20.9	0.48	0.75	Pred.
42	17.2	0.04	0.19	Obs.
43	19.8	0.34	0.68	Pred.
44	21	0.49	0.74	Pred.
45	23.4	0.85	0.95	Obs.
46	21.1	0.46	0.75	Pred.
47	20.7	0.4	0.7	Pred.
48	22.3	0.55	0.92	Obs.
49	21.3	0.51	0.79	Pred.
50	20.9	0.44	0.77	Pred.
51	20.3	0.33	0.67	Pred.
52	20.6	0.4	0.7	Pred.
53	21.5	0.53	0.7	Pred.
54	19.1	0.26	0.59	Pred.
55	17.1	0.04	0.19	Obs.
56	22.4	0.94	0.99	Obs.
57	19.6	0.26	0.49	Pred.
58	21	0.53	0.82	Pred.
59	18.2	0.14	0.35	Pred.
60	20	0.35	0.64	Pred.
61	18.3	0.17	0.38	Pred.
62	20	0.32	0.62	Pred.
63	20.3	0.37	0.7	Pred.
64	18.5	0.16	0.47	Pred.
65	18.3	0.14	0.44	Pred.
66	20.3	0.32	0.7	Pred.

Table 10.8 – Continued. Water temperature metrics from June 1 to September 30, 2021: average temperature (° C), proportion of summer when daily maximum temperature exceeded 20° C (days w/ MAX >20° C), and the proportion of summer when daily minimum temperature exceeded 20° C (days w/ MIN >20° C) for each of the 105 spatial planning units within the Medway River watershed. Data status denotes whether the data are field observation (Obs.) or a prediction (Pred.) obtained through machine learning models.

SPU ID	Average temperature (°C)	Days w/ MIN > 20°C	Days w/ MAX > 20°C	Data status
67	20.2	0.4	0.72	Pred.
68	21.7	0.6	0.83	Obs.
69	19.5	0.36	0.63	Pred.
70	19.6	0.26	0.73	Obs.
71	21.1	0.47	0.81	Pred.
72	19.9	0.36	0.7	Pred.
73	18.5	0.15	0.47	Pred.
74	20.7	0.4	0.74	Pred.
75	19.7	0.26	0.65	Pred.
76	20.6	0.41	0.82	Pred.
77	18.5	0.17	0.4	Pred.
78	20.8	0.4	0.8	Pred.
79	19.4	0.25	0.63	Pred.
80	20.9	0.44	0.79	Pred.
81	20.6	0.34	0.76	Pred.
82	22.1	0.53	0.91	Obs.
83	19.1	0.2	0.52	Pred.
84	21.5	0.59	0.81	Pred.
85	20	0.32	0.66	Pred.
86	18.6	0.14	0.48	Pred.
87	19.7	0.27	0.6	Pred.
88	19	0.18	0.58	Pred.
89	18.6	0.17	0.4	Pred.
90	19	0.1	0.68	Obs.
91	21.5	0.59	0.76	Pred.
92	18.5	0.18	0.39	Pred.
93	19.5	0.31	0.53	Pred.
94	17.9	0.15	0.48	Pred.
95	22.4	0.64	0.88	Obs.
96	22.6	0.75	0.92	Obs.
97	19.2	0.13	0.7	Obs.

98	21.5	0.6	0.85	Obs.
99	18.3	0.06	0.35	Pred.

Table 10.8 – Continued. Water temperature metrics from June 1 to September 30, 2021: average temperature (° C), proportion of summer when daily maximum temperature exceeded 20° C (days w/ MAX >20° C), and the proportion of summer when daily minimum temperature exceeded 20° C (days w/ MIN >20° C) for each of the 105 spatial planning units within the Medway River watershed. Data status denotes whether the data are field observation (Obs.) or a prediction (Pred.) obtained through machine learning models.

SPU ID	Average temperature (°C)	Days w/ MIN > 20°C	Days w/ MAX > 20°C	Data status
100	21.1	0.47	0.78	Pred.
101	17.8	0.06	0.34	Pred.
102	20.1	0.32	0.78	Obs.
103	19.7	0.25	0.65	Pred.
104	18.8	0.18	0.41	Pred.
105	16.5	0.07	0.24	Obs.
Watershed average	**20.4**	**0.39**	**0.69**	**26 observations**

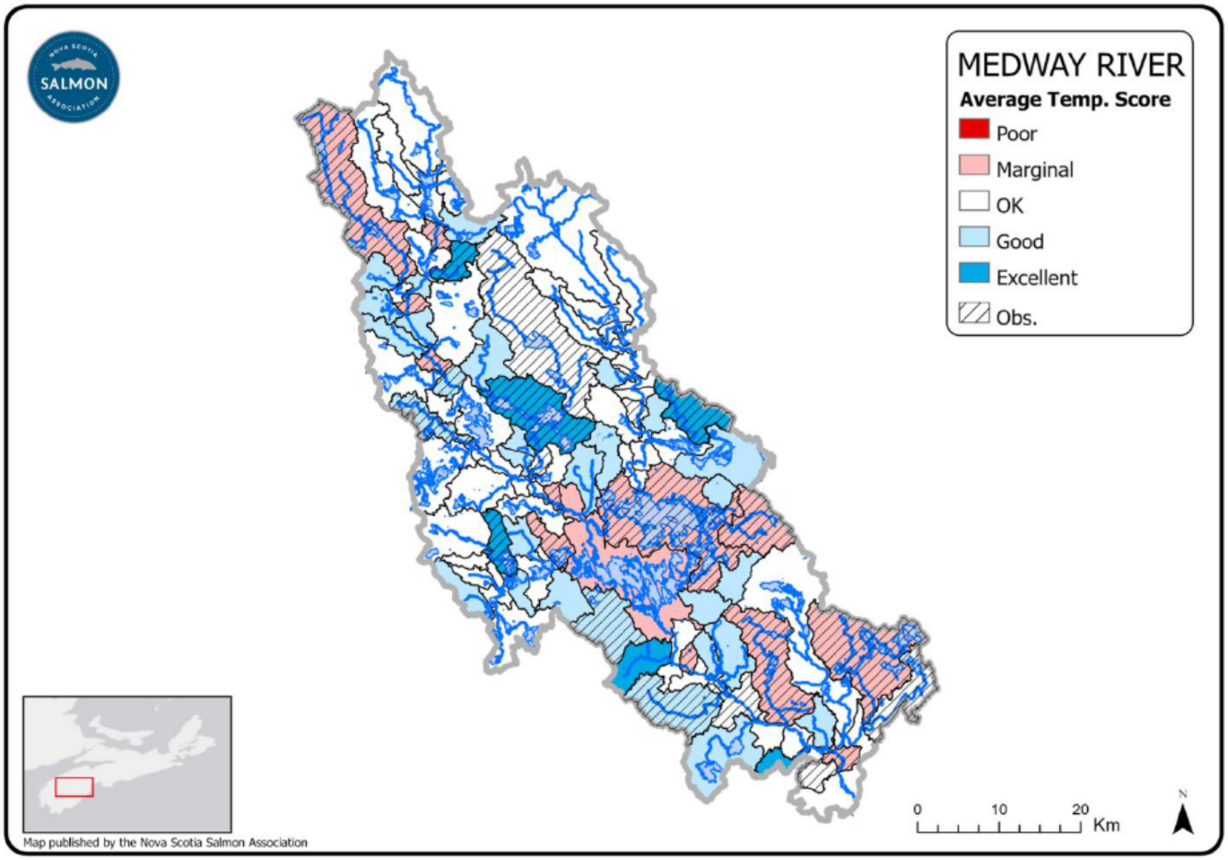

Figure 10.26 Scoring category based on average temperature in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada. Hatching lines indicate the SPUs where the data was collected and undashed SPUs show predicted values.

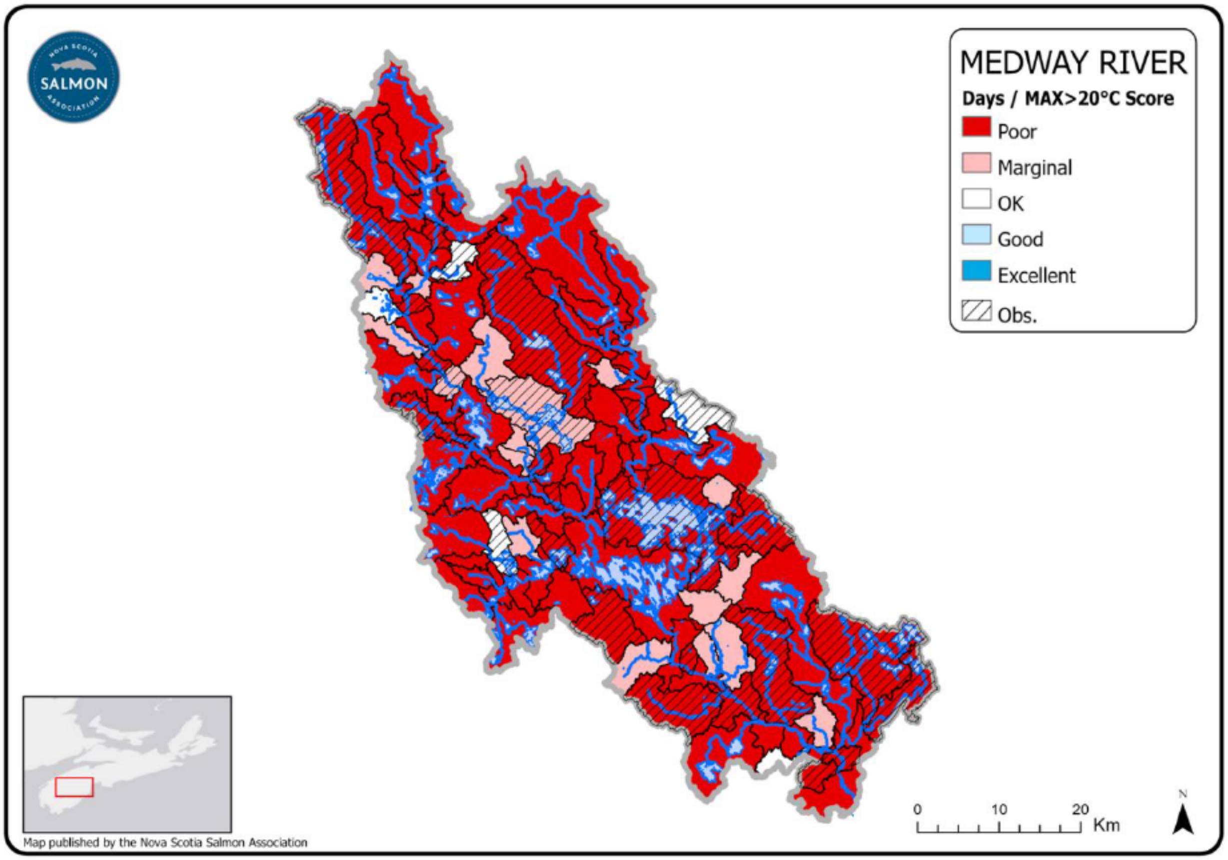

Figure 10.27 Scoring categories based on the average temperature in Celsius degrees in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada. Hatching lines indicate the SPUs where the data was collected and undashed SPUs show predicted values.

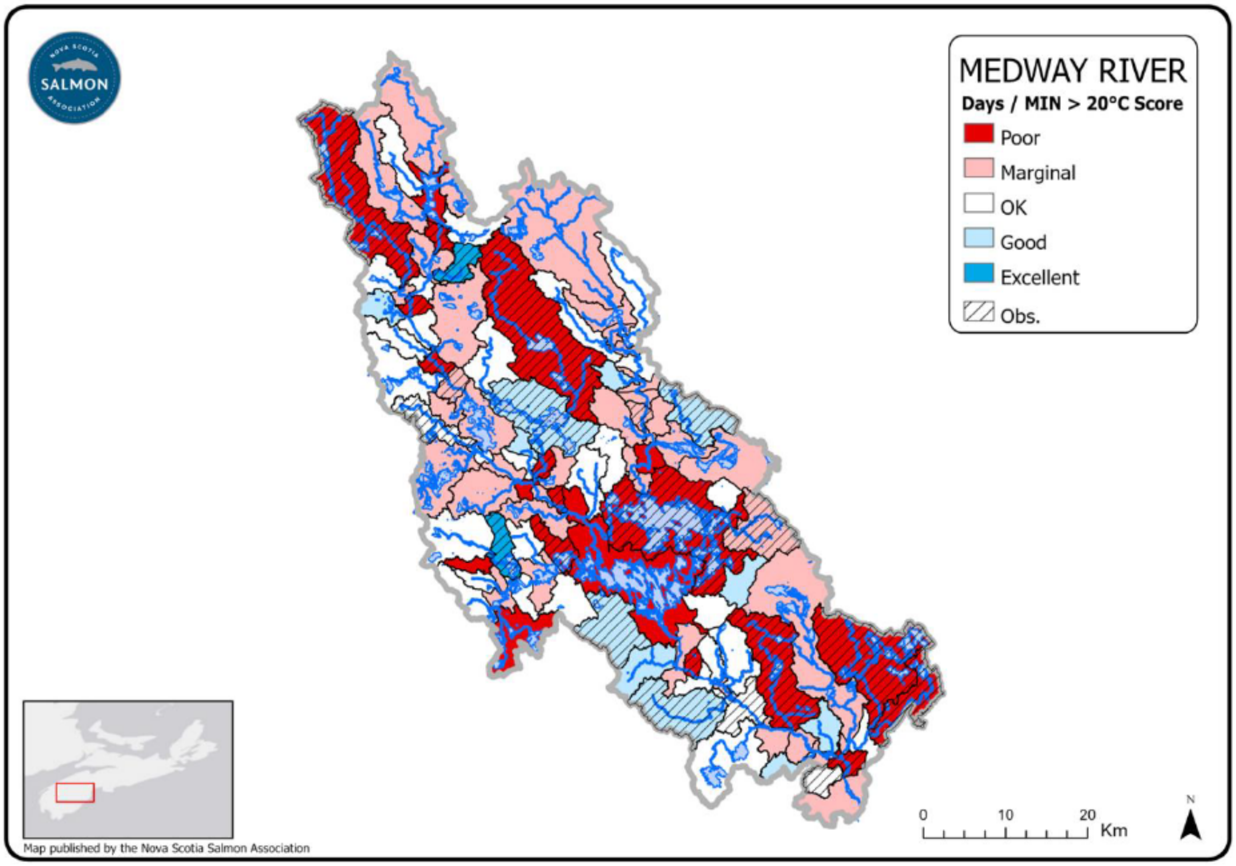

Figure 10.28 Scoring category based on the number of days with minimum temperature > 20°C in each of the 105 spatial planning units that composes the Medway River watershed in the southwestern shore of Nova Scotia, Canada. Hatching lines indicate the SPUs where the data was collected and undashed SPUs show predicted values.

10.2.5 Data Collection 2020-2022: Species distribution using eDNA

Environmental DNA sampling technique (eDNA) is a non-invasive technique used to identify the likely presence of a species in a waterbody (Shu et al. 2020). The presence of a species' DNA indicates the likely presence of that species in the river where the sample was collected. We collected samples on three occasions in the fall of 2020 at 16 sites, however analysis was possible for only 15 sites due to poor quality at one location. Analysis of eDNA samples was conducted by the Marine Gene Probe Lab at Dalhousie University and the full methods can be found in Chapter 5. Two separate types of analyses occurred: First, we specifically targeted qPCR assays to identify the presence of five native species (Atlantic Salmon, American Eel, Atlantic Whitefish, Brook Trout, and Brook Floater) and two invasive species (Smallmouth Bass and Chain Pickerel). This targeting search was relatively powerful but focused only on those species which were targeted. Samples were also analyzed using a metabarcoding approach which looks for all vertebrate species but is less powerful and therefore less likely to identify any given species.

Atlantic Salmon were recorded in only 1 of 15 sampled SPUs, located in the central portion of the watershed (SPU#38, Westfield River). In contrast, American Eel were detected in 12 of the 15 sampled SPUs. Brook Trout were detected in four SPUs, while Atlantic Whitefish and Brook Floater were absent in the Medway River watershed. The invasive species Smallmouth Bass was detected in four SPUs and Chain Pickerel was absent in the sampled SPUs (Table 7).

In addition to the 2020 eDNA samples, we also incorporated other sources of species distribution data where available. For example, Acadia University (Dr. Trevor Avery) was contracted as part of the Canada Nature Fund for Aquatic Species at Risk. Closed-site, single pass electrofishing was used to capture fish and assess diversity and catch rates at 11 tributary sites within the Medway River. Atlantic Salmon were captured at 3 of 11 sites: Westfield River (SPU#38, salmon also detected via eDNA), Cameron Brook (SPU#45, sampled via eDNA but no salmon detected) and the Medway River at South Brookfield (SPU#17). American Eel were the most widely captured species, occurring at 9 of 11 sites.

The Nova Scotia Department of Fisheries and Aquaculture also electrofished the Medway River using single pass with no barrier methodology in October 2020. Three of the eight sites sampled contained Atlantic Salmon, specifically in the main Medway River just below Eel Lake/McGowan Lake (SPU#16), the Westfield River (SPU#38) and FifteenMile Brook (SPU#94).

The Medway River Salmon Association, with support from Acadia University have deployed and operaed a rotary screw trap (RST, aka smolt wheel) at 44.1739° & -064.6593° in Charleston, NS in 2021, 2022 and 2023. They have captured Atlantic Salmon smolts and Atlantic Salmon parr, American Eel, White Suckers, Yellow Perch, Alewife and several other species in the RST.

The upstream origin of the downstream migrating Atlantic Salmon smolts is unclear. A full report is pending and the results of which will be incorporated here in subsequent drafts.

The last electrofishing effort by the Federal Department of Fisheries and Oceans involved a three-site survey in 2000 and a four-site survey in 2008. In the 2000 survey, salmon were found in 3 of 3 sites, including the Westfield River (SPU#38), Camerons Brook (SPU#45) and Fifteen Mile Brook (SPU#94). By 2008, salmon were again captured in Westfield River (SPU#38) and FifteenMile Brook (SPU#94), were captured in a new location (Petite Brook, SPU#26) but were not captured in the upper main Medway near the community of Kempt (SPU#70).

Combining the eDNA and ancillary sources of data, we interpreted the species distribution data using expert interpolation. For example, in a scenario where a length of main river is broken into three consecutive SPUs with no significant interruptions, change of habits, etc. If the most upstream SPU and the most downstream SPU were sampled and a species was detected in both, but the middle SPU was unsampled, then experts interpolation would mark the middle, unsampled SPU as likely having the species detect both above and below.

Summarizing the results above, the following statements appear true:

1) Atlantic Salmon remain present in the watershed and occupy several areas, and despite limited recent density data, their density and distribution is low relative to values prior to 1990.
2) American Eel remain widespread throughout the Medway River.
3) Smallmouth Bass are widespread but appear to primarily occupy main river and lake habitats and may be less prevalent in tributaries, particularly those without headwater lakes. Considerations of the distribution of Smallmouth Bass should be included when making decisions to address aquatic connectivity.
4) There is no evidence of Chain Pickerel within the Medway River and preventing their introduction and establishment should be a top priority.

Table 10.9- Results of eDNA analysis for the presence of the five native species (Atlantic Salmon, American Eel, Atlantic Whitefish, Brook Trout, and Brook Floater) and two invasive species (Smallmouth Bass and Chain Pickerel). SPU ID means the number identification of each sampled Spatial Planning Units (SPU) that compose the Medway River watershed in eastern shore, Nova Scotia.

	qPCR Presence / Absence					Metabarcoding
SPU ID	American Eel	Atlantic Salmon	Brook Trout	Smallmouth Bass	Chain Pickerel	Total Species Richness
11	1	0	0	0	0	5
64	*0*	*0*	*0*	*0*	*0*	7
26	1	0	1	1	0	n/a
93	0	0	0	0	0	3
33	1	0	0	0	0	7
38	1	1	1	1	0	8
45	1	0	0	0	0	4
56	1	0	0	0	0	8
66	1	0	0	0	0	11
81	0	0	1	1	0	2
82	1	0	1	1	0	8
95	1	0	0	0	0	5
96	1	0	0	0	0	3
98	1	0	0	0	0	5
102	1	0	0	0	0	9
Total	12	1	4	4	0	

NOTE - Atlantic Whitefish and Brook Floater were not found in any samples in any watershed. *n/a* denotes samples that did not return yield.

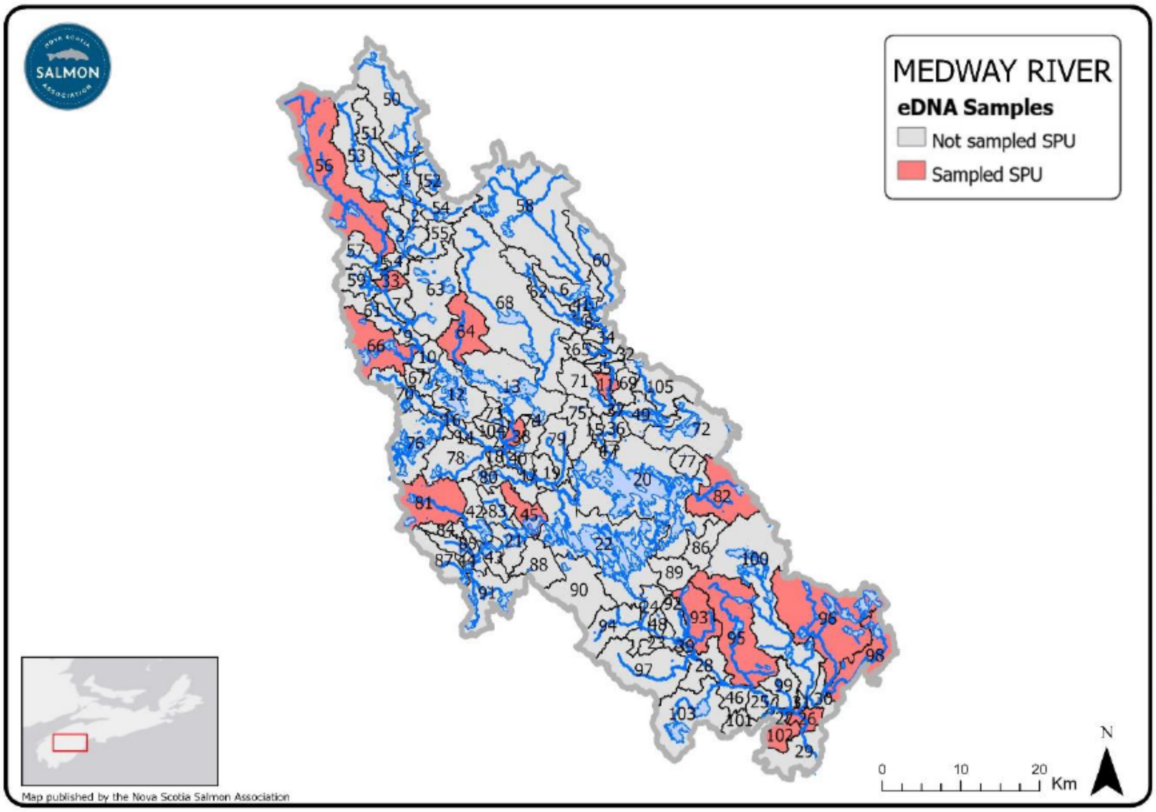

Figure 10.29 Spatial planning units - SPUs selected for eDNA samples for the presence of the target native and invasive species in the 15 sampled SPUs across the Medway River watershed in the south shore of Nova Scotia, Canada.

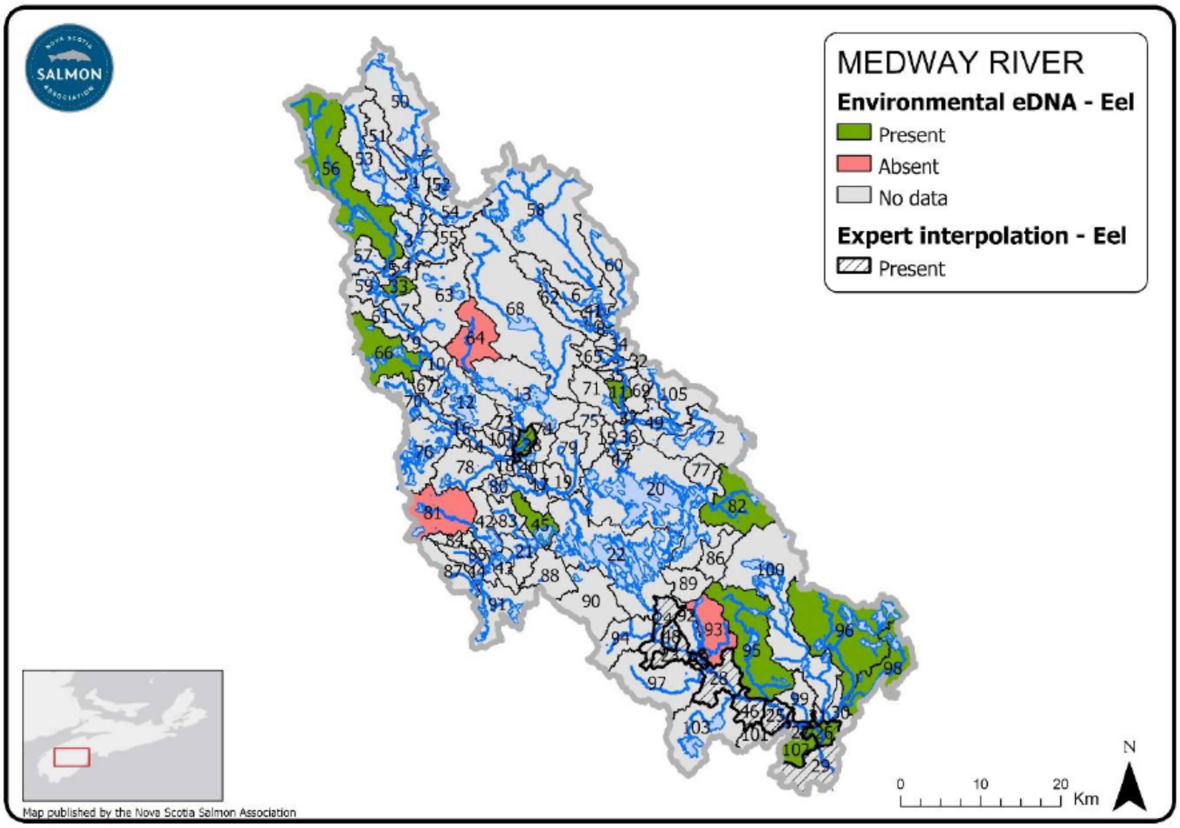

Figure 10.30 Presence /absence of American Eel across the 105 SPUs that compose the Medway River watershed in south shore, Nova Scotia. The presence / absence data from eDNA surveys were combined with presence records from experts represented by hatching lines.

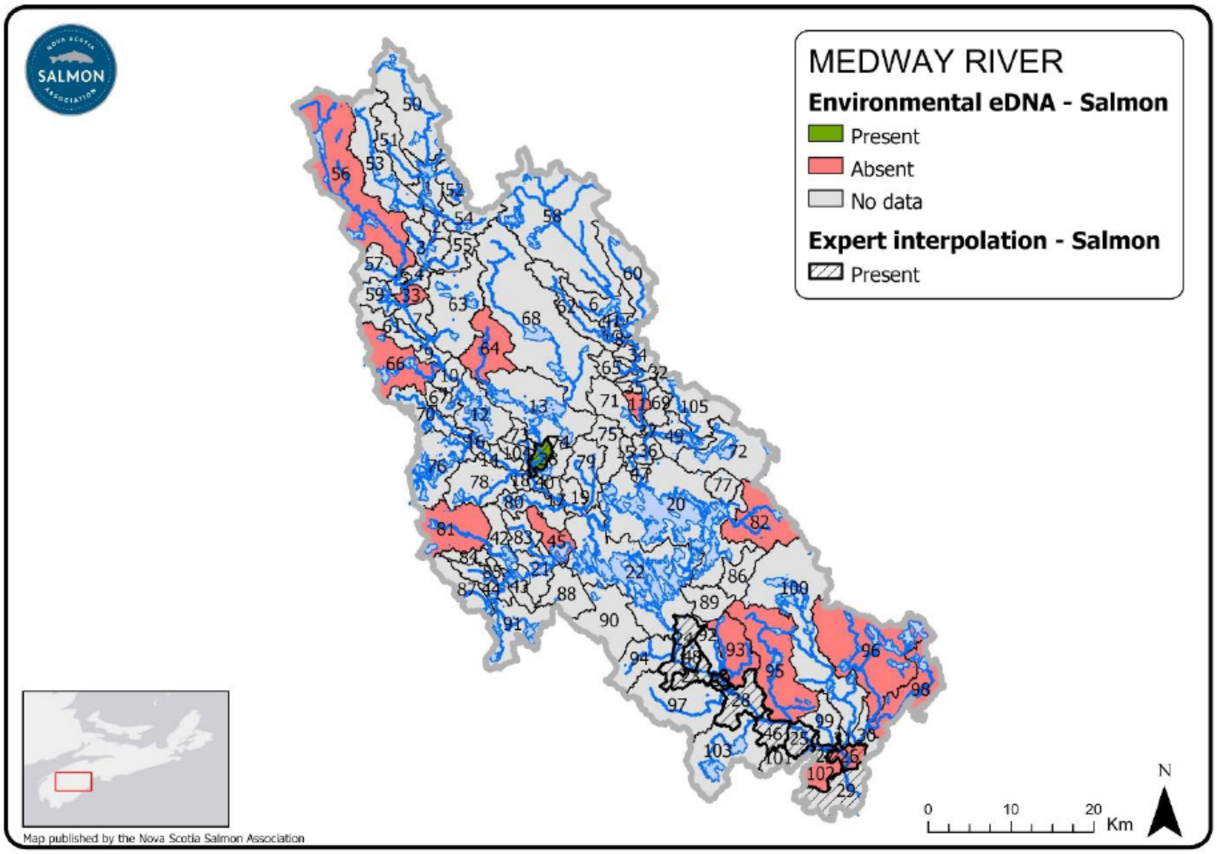

Figure 10.31 Presence /absence of Atlantic Salmon across the 105 SPUs that compose the Medway River watershed in south shore, Nova Scotia. The presence / absence data from eDNA surveys were combined with presence records from experts represented by hatching lines.

Other species and richness hotspots

Within the 15 sampled SPUs sampled for eDNA in 2020, the number of unique species ranged from 2 to 11 species (Figure 10.9). A higher number of species (> 6 species) were recorded in the upper tributaries in the northern portion, while species richness declined in the lower portion of the watershed where most of the sampled SPUs recorded less than 6 species (Figure 10.32; Table 10.9). However, across the entire watershed eDNA detected 16 unique fish species, while electrofishing earlier in the season added another (Table 10.10). Electrofishing by Acadia University at 11 sites in 2022 detected 12 species, 11 of which were identified by eDNA and also Sea Lamprey. The addition of Lamprey is likely related to the discrepancy in sampling time, with the eDNA occurring in the fall and the electrofishing occurred in the summer period when adult Sea Lamprey we in the river for spawning.

Table 10.10 - Total number of species recorded in across the entire Medway River watershed in south Nova Scotia. SPU ID means the identification number of the sampled SPUs.

Freshwater Fish Species	Genus, Species	Medway
Alewife	Alosa pseudoharengus	Yes
American Eel	**Anguilla rostrata**	Yes
Atlantic Salmon	**Salmo salar**	Yes
Atlantic Whitefish	**Coregonus huntsmani**	No
Banded Kilifish	Fundulus diaphanus	Yes
Brook Trout	Salvelinus fontinalis	Yes
Brown Bullhead	Ameiurus nebulosus	Yes
Brown Trout	Salmo trutta	No
Chain Pickerel	**Esox niger**	No
Common Shiner	Luxilus cornutus	Yes
Creek Chub	Semotilus atromaculatus	Yes
Finescale Dace *	**Chrosomus neogaeus**	Yes
Fourspine Stickleback	Apeltes quadracus	Yes
Golden Shiner	Notemigonus crysoleucas	Yes
Lake chub	Couesius plumbeus	No
Ninespine Stickleback	Pungitius sp.	Yes
Rainbow Trout	Oncorhynchus mykiss	No
Sea Lamprey	Petromyzon marinus	No
Smallmouth Bass	**Micropterus dolomieu**	Yes
Three-Spined Stickleback	Gasterosteus aculeatus	Yes
White Perch	Morone americana	No
White Sucker	Catostomus commersonii	Yes
Yellow Perch	Perca flavescens	Yes
TOTAL Fish Species		**16**

*** not previously described in NS**

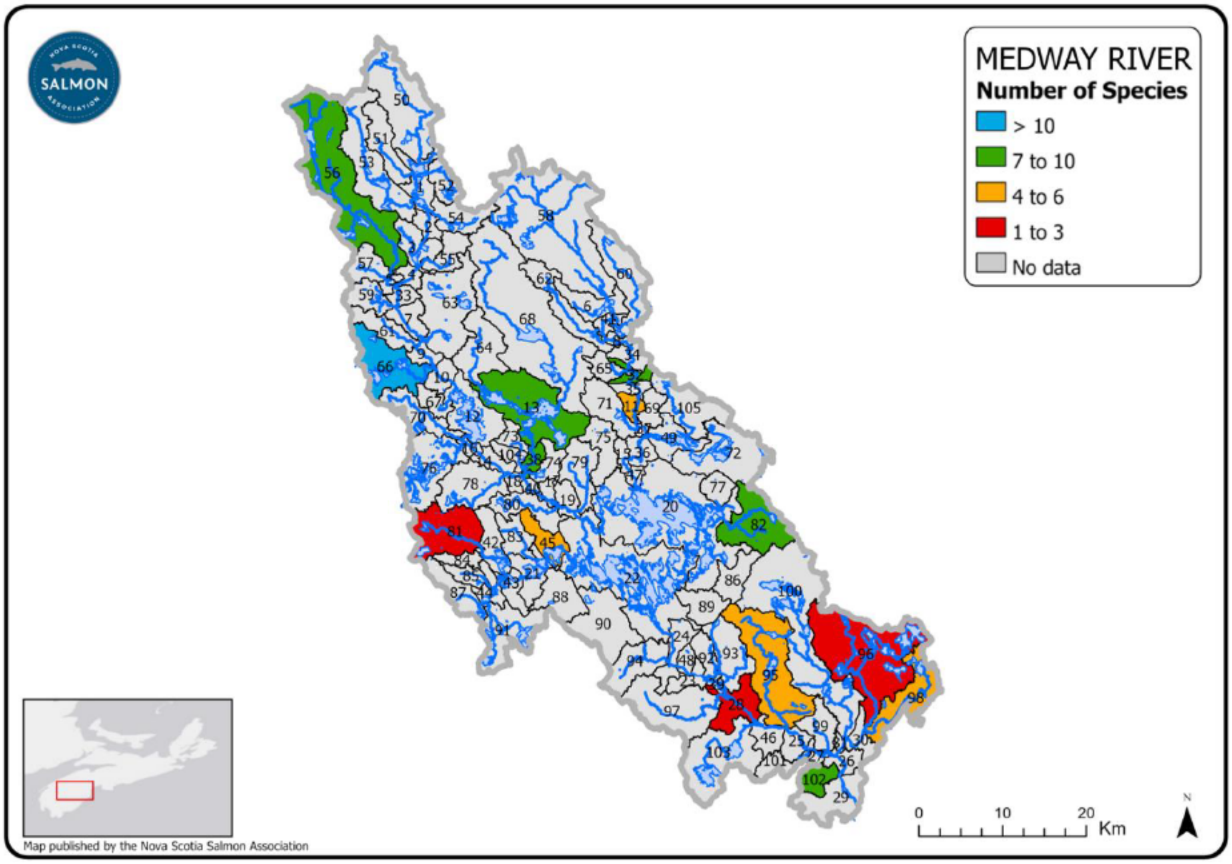

Figure 10.32 Number of species per spatial planning units (SPUs) based on eDNA samples collected in 5 SPUs across the Medway River watershed on the eastern shore of Nova Scotia. Unsampled SPUs are in gray (No data).

10.2.6 Aquatic connectivity (barrier) assessment

The connectivity status of the Medway River system is one of the least studied major systems in the Southern Uplands. The Nova Scotia Salmon Association is not currently aware of any full assessments of road crossings in tributary units, though there are a small number of dam assessments as well as a small number of rapid road crossing assessments. Additionally, this system has a number of high slope elevation areas and waterfalls which may present barriers to diadromous species.

HIGH SLOPE AREAS

The lower reaches of the main branch are characterized by fast flowing rapid systems, and a number local "falls". The use of the word falls in this case is more indicative of terminology used by anglers to characterize fast moving rapids and do not necessarily mean waterfalls as used traditionally.

Highest slope PLUs

PLU	Average 10m slope %	Maximum Slope in Unit %
92	0.96	11.63
99	0.91	18.14
57	0.87	32.34
61	0.83	13.50
86	0.79	3.15

NOTABLE BARRIERS

The McGowan Lake Dam, situated on the southern outflow of McGowan Lake and part of the Harmony power system, separates the Northen sections of the Medway River from its southern reaches near Westfield Nova Scotia. While the power generation of this facility was decommissioned in 2017, the concrete spillway and fish ladder still remain. It is unknown the degree to which fish passage is being impeded, as the fish passage infrastructure is high flow and designed primarily to accommodate mature Atlantic Salmon. Habitat suitability assessments have not been conducted in the upper portions of the Medway, however it is believed from local sources that limited salmon spawning habitat exists upriver of the structure.

Smallmouth bass, an invasive predator, have been found below the fishway but have not yet been confirmed above, and there is local speculation that current fishway is operating as a barrier to invasive species. While it has been speculated that the typically high flow rates of the ladder prevent upstream migration except for potential mature Atlantic Salmon, local stakeholders have suggested that Gaspereau have been caught regularly above the structure.

ROAD CROSSING DENSITY

The planning unit with the highest concentration of crossings is main unit 20, however this is disproportionately high due to the proximity of housing developments to Molega lake. As such there are a large number of small roads and driveways crossing many first order or small streams. Similarly tributary unit 56 has a disproportionately high degree of road crossings, all of which are currently unassessed. While comprised primarily of the third order sections of the West Branch of the Medway, a singular road crosses through wetland sections multiple times over a very short distance.

The highest densities of road crossings are located in the Eastern portions of the watershed, particularly upstream of the town of Pleasant River and below Pleasant River Lake, these include planning units: 11, 34, and 60.

[Map of Medway Barrier Crossing Scores – Under Development]

Bowlby et al. (2014) noted that of the estimated 6.76 million m^2 of suitable fluvial salmon rearing habitat within the Medway River watershed (O'Connell et al. 1997), approximately 17.7% or 1.20 million m^2 of this is above barriers described in the national hydro network (NHN) aquatic barrier database, most of which lies above the McGowan Lake dam. Applying the same calculations used by O'Connell et al. (1997) to estimate the number of salmon required to fully seed available spawning habitat and set conservation spawner requirements, the habitat above NHN barriers within the Medway is capable of supporting approximately 1,585 returning adult Atlantic Salmon (1,278 1SW fish and 307 MSW fish).

10.3 OVERALL HABITAT METRIC SCORES

In development but see map below

10.3.1 Habitat Metrics Score results 'as-is' scenario

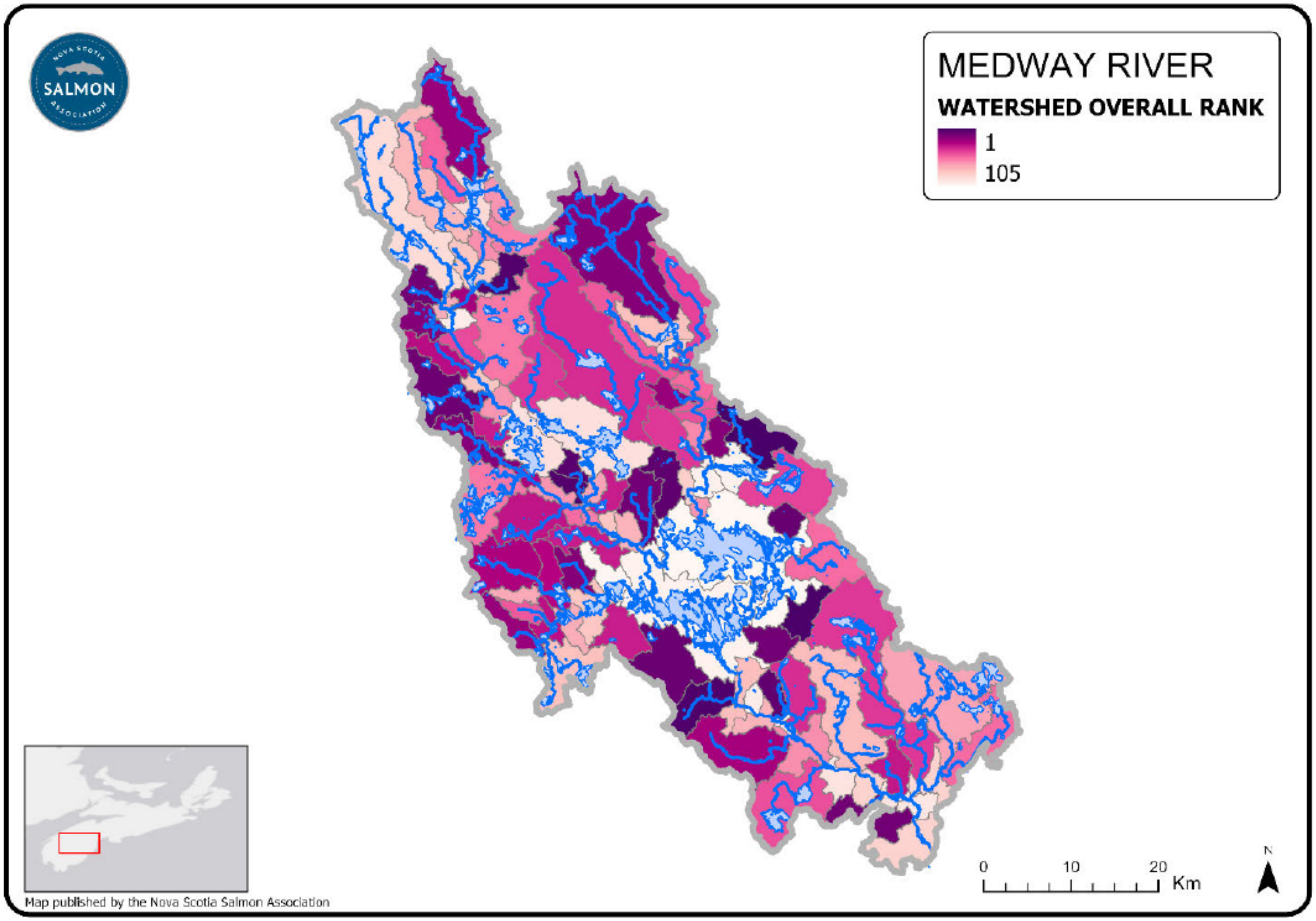

Figure 10.34 – Results of the weighted scoring model which ranks each of the 105 SPUs within the Medway River based on as the best (1) and worst (105) habitat under current conditions.

10.4 PRIORITY AREAS FOR RESTORATION

In development

10.5 SUGGESTED RESTORATION ACTIVITIES

In development

10.6 CHAPTER-SPECIFIC REFERENCES

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