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CAPE COD COMMISSION

Technologies Matrix

REFERENCES, NOTES, AND ASSUMPTIONS
2017 UPDATE

(SEE NOTE 29)

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Table of Contents

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Constructed Wetlands - Surface Flow

(1) Average Removal Rate (P 419) and Median Total Nitrogen Removal Rate (P 308), Median Phosphorus Removal Rate (P 378) from Kadlec and Wallace, Treatment Wetlands 2nd Ed.

- **LINK:** https://www.sswm.info/sites/default/files/reference_attachments/KADLEC%20WALLACE%202009%20Treatment%20Wetlands%202nd%20Edition_0.pdf

(2) Range of wetland costs (P 132-133) and Wastewater effluent concentrations (converted to lbs/gal) data taken from Table 3-1 from Constructed Wetlands Treatment of Municipal Wastewaters. EPA.1999

- **LINK:** http://water.epa.gov/type/wetlands/restore/upload/constructed-wetlands-design-manual.pdf

(3) Range of O&M values from Jim Kreissl, Constructed Wetlands Treatment for Nutrient Treatment for Nutrient Reduction, Presentation at POTW Nutrient Reduction and Efficiency Workshop, 2008.

- **LINK:** http://www.tetratech-ffx.com/potwconf/pdf/112008_1200_Kreissl.pdf

(4) Average Gal./day/acre derived from Table 2. Ogden, Michael. Costs of Constructed Wetland Systems. Prepublication copy for presentation at WEFTEC '98, 1998.

- **LINK:** http://www.brownandcaldwell.com/technicalPapersAbstract.asp?TPID=5720

(5) Flow range of 5 precedents evaluated by Offshoots, Inc., June 2013.

(6) 1 acre of FWS CTW at 330 gpd = 45-70 homes/acre for Total Nitrogen. Assumptions : Q = 330 gpd (1.25 m3/d); Ci = 20 mg/l (Total N); Ce = 5 mg/l (Total N); k (areal rate constant) = 10-20 m/yr., C* = 1.5 mg/l (background value). Equates to 0.010 to 0.020 acres/330 gpd.

(7) Influent Concentrations: (a) For Primary WWTF Effluent assume: (N) =.0004lbs/gal (52.5mg/l), (P)=7.92×10^{-5} lbs/gal (9.5mg/l), and (b) For Secondary

WWTF effluent assume: (N)=.0001 lbs/gal (15mg/l), and (P)=2.92 × 10-5 lbs/gal (3.5mg/l).

(8) Improving Winter Performance of Constructed Wetlands for Wastewater Treatment in Northern China: A Review

- **LINK:** http://LINK.springer.com/article/10.1007%2Fs13157-013-0444-7#

(9) USEPA Wetlands Subsurface Flow Fact Sheet

- **LINK:** https://19january2017snapshot.epa.gov/sites/production/files/2015-06/documents/wetlands-subsurface_flow.pdf

(10) Without the use of water aeration such as Solar Bees, Free Water Surface systems will not typically meet discharge limits for BOD and TSS . However, water aeration augments protozoan, invertebrate, and fish populations which harvest large amounts of algae. estimates/acre.

> *Systems not designed to remove phosphorus. Phosphorus removal in these smaller systems requires lengthy retention times and/or use of specialized media to increase sorption
>
> **Based on 44,000GPD / 2.08 acre total treatment area for Fields of St Croix constructed wetland system in Lake Elmo, MN

(11) Calculation Basis for Calculator - For No Collection System - (a) Need to add effluent disposal costs; (b) Use pricing for infiltration basins ($3 to $5/sqft). Average $4/sqft; (c) Metric is gpd; (d) Assumed flow for infiltration basin is approximately 4 gpd/sqft (fine to course sandy soils); and (e) Modify construction costs by adding the following - input flow (gpd) divided by 4 gpd/sqft times $4/sqft.

(12) Calculation Basis for Calculator - For Collection System, Treatment and Disposal - (a) Need to add collection, system treatment and effluent disposal costs; (b) Use pricing for infiltration basins ($3 to $5/sqft). Average $4/sqft; (c) Metric is gpd; (d) Assumed flow for infiltration basin is approximately 4 gpd/sqft (fine to course sandy soils); (e) Modify construction costs by adding the following - input flow (gpd) divided by 4 gpd/sqft times $4/sqft (f) • Use pricing for collection system from matrix ($3 to $5/sqft). Average $4/sqft (g) Need equation for size (cost) of collection system based on metric of gpd. Alternative is to use costs from MVP after targeting area to sewer; and (h) Need costs or cost curve to size and cost a primary WWTF. Alternative is to use costs from MVP after targeting area to sewer.

Constructed Wetlands - Subsurface Flow

(1) Average Removal Efficiency (P 417) and Median Total Nitrogen Removal Rate (P 309) from Kadlec and Wallace. Treatment Wetlands, 2nd Ed.

- **LINK:** https://www.sswm.info/sites/default/files/reference_attachments/KADLEC%20WALLACE%202009%20Treatment%20Wetlands%202nd%20Edition_0.pdf

(2) Range of cost and O&M values adjusted for inflation from Jim Kreissl, Constructed Wetlands Treatment for Nutrient Treatment for Nutrient Reduction, Presentation at POTW Nutrient Reduction and Efficiency Workshop, 2008.

- **LINK:** http://www.tetratech-ffx.com/potwconf/pdf/112008_1200_Kreissl.pdf

(3) Average Removal Rate from Vymazal Jan. Removal of Phosphorus in Constructed Wetlands with Horizontal Sub-Surface Flow in the Czech Republic. Water, Air and Soil Pollution: Focus. June 2004, Volume 4, Issue 2-3, pp. 657-670.

- **LINK:** https://LINK.springer.com/article/10.1023/B:WAFO.0000028385.63075.51

(4) Gal./day/acre Value averaged from Table 6. Ogden, Michael. Costs of Constructed Wetland Systems. Prepublication copy for presentation at WEFTEC '98, 1998.

- **LINK:** http://www.brownandcaldwell.com/technicalPapersAbstract.asp?TPID=5720

(5) Data on Phosphorus removal from Subsurface flow wetlands is highly varied and dependent on retention time and media used. This value is calculated at 50% of the phosphorus removal rate of a FWS constructed wetland system.

(6) 1 acre of SSF CTW will treat 50-75 homes/acre Total Nitrogen at 330 gpd. Assumptions: Q= 330 gpd (1.25 mg/l); Ci = 20 mg/l; Ce = 5 mg/l (TN), k (areal removal rate constant): 4-15 m/yr. C* = 0 mg/l (background). Equates to 0.015 to 0.025 acres/330 gpd.

(7) USEPA Wetlands Subsurface Flow Fact Sheet

LINK: https://19january2017snapshot.epa.gov/sites/production/files/2015-06/documents/wetlands-subsurface_flow.pdf

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Constructed Wetlands - Groundwater Treatment

(1) Removal efficiency based on Fields of St. Croix constructed wetland project. Data provided by Bruce Douglas of Natural Systems Utilities. 2012. Interview.

(2) Median Total Nitrogen Removal Rate from Kadlec and Wallace. Treatment Wetlands 2nd Ed. (p 309).

- **LINK:** https://www.sswm.info/sites/default/files/reference_attachments/KADLEC%20WALLACE%202009%20Treatment%20Wetlands%202nd%20Edition_0.pdf

(3) Capital costs of Fields of St. Croix constructed wetlands system derived by multiplying number of homes connected to system (133) by capital cost per connection ($5524) to derive total capital cost (731,159). This number was then divided by the total treatment area of the project (2.08 acres) to give $351,519/acre which was adjusted for inflation. Data derived from Table 2. Costs for Cluster Wastewater Systems. Scott. D Wallace and Dennis F. Hallahan. Proceedings of the 2005 National Onsite Wastewater Recycling Assoc. National Conference.

(4) O&M costs derived by multiplying monthly service charge per connection by total number of connections for the Fields of St. Croix project. The result was then divided by the total treatment area of the project (2.08 acres). Table 3. Costs for Cluster Wastewater Systems. Scott. D Wallace and Dennis F. Hallahan. Proceedings of the 2005 National Onsite Wastewater Recycling Assoc. National Conference.

(5) Wastewater effluent concentrations converted to lbs/gal. Data taken from Table 3-1. Constructed Wetlands Treatment of Municipal Wastewaters. EPA. 1999.

(6) Costs per connection were extrapolated based on total number of connections to derive capital cost. Capital costs were then divided by design flow (GPD) for each project to derive $/Gal. Data from Tables 2 and 3. Costs for Cluster Wastewater Systems. Scott. D Wallace and Dennis F. Hallahan. Proceedings of the 2005 National Onsite Wastewater Recycling Assoc. National Conference.

(7) Monthly service charge costs were multiplied by number of homes connected to system and then by 12 to determine yearly service charge. This product was then divided by design flow to derive $/gal/yr. However, this is the cost to users, not

necessarily the O&M cost, because it includes $ paid by users for future necessary replacements. Data from Tables 2, 3 and 4. Costs for Cluster Wastewater Systems. Scott. D Wallace and Dennis F. Hallahan. Proceedings of the 2005 National Onsite Wastewater Recycling Assoc. National Conference.

(8) Flow range of 3 precedents evaluated by Offshoots, Inc., June 2013.

(9) 1 acre of SSF CTW will treat 50-75 homes/acre Total Nitrogen at 330 gpd. Assumptions: Q= 330 gpd (1.25 mg/l); Ci = 20 mg/l; Ce = 5 mg/l (TN), k (areal removal rate constant): 4-15 m/yr. C* = 0 mg/l (background). Equates to 0.015 to 0.025 acres/330 gpd.

(10) USEPA Wetlands Subsurface Flow Fact Sheet

- **LINK:** https://19january2017snapshot.epa.gov/sites/production/files/2015-06/documents/wetlands-subsurface_flow.pdf

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Hydroponic Treatment

(1) Range of summary denitrification numbers provided by John Todd Ecological Design.

- **LINK:** http://www.toddecological.com/index.php?id=projects

(2) Cost/gallon averaged from 3 living machine projects. EPA. Wastewater Technology Fact Sheet: Living Machines. 2002

- **LINK:** https://19january2017snapshot.epa.gov/www3/npdes/www3/pubs/living_machine.pdf

(3) Averaged mass reduction based on Nitrogen influent-effluent numbers provided for 4 Eco-machine projects and 890,000 gal/27,000 sq. ft. facility size provided by Todd Ecological Design.

(4) Data based on 890,000 gal/day facility requiring 27,000 sq.ft (0.61 acres) by John Todd Ecological Design.

(5) Data derived from South Burlington Living machine data only - 80,000 gpd system removed 5548 lbs of nitrogen/day at a capital cost of $1.7 million dollars, 0.14 acre site cost $70,625 to run annually, $70,625 annual O&M cost / 5,548 lbs of N removed / year

- **LINK:** http://www.toddecological.com/data/uploads/casestudies/jtedcasestudy_southburlington.pdf

(6) From Eco-Cities to Living Machines: Principles of Ecological Design, 1994, ISBN Paperback 9781556431500

- **LINK:** https://www.northatlanticbooks.com/shop/from-eco-cities-to-living-machines/

Phytoirrigation

(1) CH2HMill, 2012, J. Smeasrod Interview, Offshoots, Inc. Precedent Study- 3 projects.

(2) Nitrogen concentrations in groundwater are difficult to test. This is the minimum standard that is known to be removed, but the numbers are likely much higher.

(3) Cost per acre can be as low as 5,000 when small cuttings and no irrigation is used.

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Stormwater BMP Phytobuffers

(1) CH2HMill, 2012, J. Smeasrod Interview, Offshoots, Inc. Precedent Study- 3 projects.

(2) Nitrogen concentrations in groundwater are difficult to test. This is the minimum standard that is known to be removed, but the numbers are likely much higher.

(3) Cost per acre can be as low as 5,000 when small cuttings and no irrigation is used.

Stormwater BMP - Vegetated Swale

(1) Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management, ASCE Journal of Environmental Engineering, Vol. 139, No. 7, July 1, 2013, James J. Houle; Robert M. Roseen, Ph.D., P.E.; Thomas P. Ballestero, Ph.D., P.E.; Timothy A. Puls; and James Sherrard, Jr.

- **LINK:** https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/Houle_JEE_July-2013.pdf

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Stormwater BMP - Gravel Wetland

(1) Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management, ASCE Journal of Environmental Engineering, Vol. 139, No. 7, July 1, 2013, James J. Houle; Robert M. Roseen, Ph.D., P.E.; Thomas P. Ballestero, Ph.D., P.E.; Timothy A. Puls; and James Sherrard, Jr.

- **LINK:** https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/Houle_JEE_July-2013.pdf

(2) Subsurface Gravel Wetland, Design Specifications, June 2009, University of New Hampshire Stormwater Center.

- **LINK:** https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/unhsc_gravel_wetland_specs_6_09.pdf

(3) Low Impact Best Management Practice (BMP) Information Sheet, Constructed Stormwater Subsurface Gravel Wetland, January 2009, Charles River Watershed Association

- **LINK:** http://www.crwa.org/hs-fs/hub/311892/file-642204307-pdf/Our_Work_/Blue_Cities_Initiative/Resources/Stormwater_BMPs/CRWA_Gravel_Wetland.pdf

Stormwater: Bioretention / Soil Media Filters

(1) A Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management, ASCE Journal of Environmental Engineering; January 25, 2013

- **LINK:** https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/asce_jee_maintenance.pdf

(2) University of New Hampshire Stormwater Center, 2013 Annual Report

- **LINK:** https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/docs/UNHSC.2012Report.10.10.12.pdf

(3) University of New Hampshire Stormwater Center, 2009 Biannual Report

- **LINK:** https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/2009_unhsc_report.pdf

(4) EPA Fact Sheet: Bioretention Winogradoff, 2001

- **LINK:** https://nepis.epa.gov/Exe/ZyPDF.cgi/200044BE.PDF?Dockey=200044BE.PDF

(5) Design of Stormwater Filtering Systems , 1996, R. Claytor, T. R. Schueler

- **LINK:** https://owl.cwp.org/?mdocs-file=4553

(6) US DOT, Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring - Fact Sheet - Filter Strips

- **LINK:** https://ntl.bts.gov/lib/47000/47100/47151/FHWA-EP-00-002_Stormwater_Best_Management_Practices.pdf

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(7) State of Vermont, State of the Practice: Enhanced Nutrient Removal in Stormwater Treatment

(8) USEPA Stormwater Technology Fact Sheet - Bioretention

- **LINK:** https://nepis.epa.gov/Exe/ZyPDF.cgi/200044BE.PDF?Dockey=200044BE.PDF

Stormwater: Constructed Wetlands

(1) A Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management, ASCE Journal of Environmental Engineering; January 25, 2013

- **LINK:** https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/asce_jee_maintenance.pdf

(2) University of New Hampshire Stormwater Center, 2013 Annual Report

- **LINK:** https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/docs/UNHSC.2012Report.10.10.12.pdf

(3) In general very similar principals, removal and sizing/removal rates as FWS wetlands but need to take into consideration episodic flow events vs. regular flow events.

(4) USEPA Wetlands Subsurface Flow Fact Sheet

- **LINK:** https://19january2017snapshot.epa.gov/sites/production/files/2015-06/documents/wetlands-subsurface_flow.pdf

Aquaculture - Shellfish

(1) Carmichael, R.H. and W. Walton, H. Clark, June 2012, Bivalve Enhanced Nitrogen Removal From Coastal Estuaries

- **LINK:** http://www.auburn.edu/~wcw0003/products/publications/carmichael-rh-w-walton--h.html

(2) The Nature Conservancy: Oyster Reef Building and Restoration for Coastal Protection

- **LINK:** https://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/louisiana/oyster-reef-restoration-in-louisiana.xml

(3) Assessment of Oyster Reefs in Lynnhaven River as a Chesapeake Bay TMDL Best Management Practice, MacSisson, Lisa Kellogg, Mark Luckenbach, Rom Lipcius, Allison Colden, Jeff Cornwell, and Michael Owens Final Report to the U. S. Army Corps of Engineers, Norfolk District

- **LINK:** http://web.vims.edu/GreyLit/VIMS/sramsoe429.pdf

(4) Various studies have quantified removal rates, though there is variation depending on shellfish type and environmental conditions.

(5) Estuarine Fish and Shellfish Species in U.S. Commercial and Recreational Fisheries: Economic Value as an Incentive to Protect and Restore Estuarine Habitat, K. A. Lellis-Dibble, K. E. McGlynn, and T. E. Bigford, November 2008

- **LINK:** https://permanent.access.gpo.gov/LPS116534/nmfs/spo.nmfs.noaa.gov/tm/TM90.pdf

(6) Bay Area Monitor, Scientists Set Seashells by the Seashore, Aleta George, October 1, 2013

- **LINK:** http://bayplanningcoalition.org/wp-content/uploads/2013/10/Bay-Area-Monitor-Seashells-by-the-Seashore.pdf

(7) Range of 250 to 1,000 Kg of N per acre based ongoing pilot studies in Falmouth, MA and Wellfleet, MA. Analysis uses a conservative value of 250 Kg of N per acre.

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(9) Kellogg, Lisa, Virginia Inset of Marine Science, Denitrification and Nutrient Assimilation on a Restored Oyster Reef, May 2013

- **LINK:** http://www.int-res.com/abstracts/meps/v480/p1-19/

(10) Rice, Michael A,, Et. Al., Changes in Shell and Soft Tissue Growth, Tissue Compositions of Quahogs and Soft-Shelled Clams in Response to Eutrophic Driven Changes in Food supply and Habitat. Boston University, Journal of Experimental Marine Biology and Ecology. August 2004

(11) STAC Report, Evaluation of the Use of Shellfish as a Means of Nutrient Reduction in the Chesapeake Bay, September, 3013d

(12) Circle C Oyster Ranchers Association: http://www.oysterranching.com/background.html

(13) Food and Agricultural Organization of the United States: Hatchery Culture of Bivalves - Fisheries Technical Paper 471

- **LINK:** http://www.fao.org/docrep/007/y5720e/y5720e02.htm

(14) Rose et al. 2014 Nutrient Bioextraction: Encyclopedia of Sustainability Science and Technology, DOI 10.1007/978-1-4939-2493-6_944-1

- **LINK:** https://www.researchgate.net/publication/292490045_Nutrient_Bioextraction

(15) Kim et al. 2015

(16) Reitsma, J. et al. 2017 "Nitrogen extraction potential of wild and cultured bivalves harvested from nearshore waters of Cape Cod, USA. Elsevier Vol 116, Issues 1-2, pp. 175-181.

- **LINK:** http://www.sciencedirect.com/science/article/pii/S0025326X16310761?via%3Dihub

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Aquaculture - Shellfish, Nursery Culture

(1) Reitsma, J. et al. 2017 "Nitrogen extraction potential of wild and cultured bivalves harvested from nearshore waters of Cape Cod, USA. Elsevier Vol 116, Issues 1-2, pp. 175-181.

- **LINK:** http://www.sciencedirect.com/science/article/pii/S0025326X16310761?via%3Dihub

Aquaculture - Mariculture

(1) Carmichael, R.H. and W. Walton, H. Clark, June 2012, Bivalve Enhanced Nitrogen Removal From Coastal Estuaries

- **LINK:** http://www.auburn.edu/~wcw0003/products/publications/carmichael-rh-w-walton--h.html

(2) The Nature Conservancy: Oyster Reef Building and Restoration for Coastal Protection

- **LINK:** https://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/louisiana/oyster-reef-restoration-in-louisiana.xml

(3) Assessment of Oyster Reefs in Lynnhaven River as a Chesapeake Bay TMDL Best Management Practice, MacSisson, Lisa Kellogg, Mark Luckenbach, Rom Lipcius, Allison Colden, Jeff Cornwell, and Michael Owens Final Report to the U. S. Army Corps of Engineers, Norfolk District

- **LINK:** http://web.vims.edu/GreyLit/VIMS/sramsoe429.pdf

(4) Various studies have quantified removal rates, though there is variation depending on shellfish type and environmental conditions.

(5) Bay Area Monitor, Scientists Set Seashells by the Seashore, Aleta George, October 1, 2013

- **LINK:** http://bayplanningcoalition.org/wp-content/uploads/2013/10/Bay-Area-Monitor-Seashells-by-the-Seashore.pdf

(6) Range of 250 to 1,000 Kg of N per acre based ongoing pilot studies in Falmouth, MA and Wellfleet, MA. Analysis uses a conservative value of 250 Kg of N per acre.

(7) Kellogg, Lisa, Virginia Inset of Marine Science, Denitrification and Nutrient Assimilation on a Restored Oyster Reef, May 2013

- **LINK:** http://www.int-res.com/abstracts/meps/v480/p1-19/

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(8) Rice, Michael A,, Et. Al., Changes in Shell and Soft Tissue Growth, Tissue Compositions of Quahogs and Soft-Shelled Clams in Response to Eutrophic Driven Changes in Food supply and Habitat. Boston University, Journal of Experimental Marine Biology and Ecology. August 2004

(9) STAC Report, Evaluation of the Use of Shellfish as a Means of Nutrient Reduction in the Chesapeake Bay, September, 3013d

(10) Circle C Oyster Ranchers Association: http://www.oysterranching.com/background.html

(11) Food and Agricultural Organization of the United States: Hatchery Culture of Bivalves - Fisheries Technical Paper 471

- **LINK:** http://www.fao.org/docrep/007/y5720e/y5720e02.htm

Phytoremediation

(1) Sand Creek Consultants, 2012, Chris Rog Interview- Offshoots, Inc. precedent study - 4 projects

- **LINK:** http://sand-creek.com/

(2) Nitrogen concentrations in groundwater are difficult to test. This is the minimum standard that is know to be removed, but the numbers are likely much higher.

(3) Cost per acre can be as low as 5,000 when small cuttings and no irrigation is used. Best if used close to higher nitrogen source. closer to source the better to overcome dispersion or tree use enough water that they pull form a larger area through a cone of depression.

(4) USEPA phytotechnologies Fact Sheet

- **LINK:** https://clu-in.org/download/remed/phytotechnologies-factsheet.pdf

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Permeable Reactive Barriers (PRBs) - Trench Method (Aquifer Thickness - 30 feet)

(1) Interstate Technology & Regulatory Council, PRB Technology Update, 2011

- **LINK:** http://www.clu-in.org/conf/itrc/prbtu/prez/ITRC_PRBUpdate_092012ibtpdf.pdf

(2) Construction cost based on 3 foot wide trench at 24 feet deep.

(3) Groundwater denitrification capacity and nitrous oxide flux of former fringing salt marshes filled with human-transported materials

- **LINK:** http://LINK.springer.com/article/10.1007/s11252-012-0266-z

(4) CICEET - Effectiveness of Reactive Barriers for Reducing N-Loading to the Coastal Zone - 02-28-08

- **LINK:** https://www.researchgate.net/publication/252506355_Effectiveness_of_Reactive_Barriers_for_Reducing_N-Loading_to_the_Coastal_Zone

(5) Gallons per day (GPD) in Column M assumes a groundwater flow of 2 ft/day or 2 cubic feet of groundwater flowing for every cubic foot of PRB times the depth (in feet) of the saturated portion of the PRB treating groundwater.

Permeable Reactive Barriers (PRBs) - Injection Well Method

(1) Interstate Technology & Regulatory Council, PRB Technology Update, 2011

- **LINK:** http://www.clu-in.org/conf/itrc/prbtu/prez/ITRC_PRBUpdate_092012ibtpdf.pdf

(2) Construction cost based on 3 foot wide trench at 24 feet deep.

(3) Groundwater denitrification capacity and nitrous oxide flux of former fringing salt marshes filled with human-transported materials

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- **LINK:** https://www.researchgate.net/publication/252506355_Effectiveness_of_Reactive_Barriers_for_Reducing_N-Loading_to_the_Coastal_Zone

(5) Gallons per day (GPD) in Column M assumes a groundwater flow of 2 ft/day or 2 cubic feet of groundwater flowing for every cubic foot of PRB times the depth (in feet) of the saturated portion of the PRB treating groundwater.

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Fertigation Wells – Turf & Cranberry Bog

(1) Construction cost based on the well being 8 to 12-inch in diameter and 20 to 30 feet deep.

Toilets: Composting

(1) 95% of average nutrient mass excreted per person per day.

- **LINK:** Previously http://richearthinstitute.org/?page_id=739, but no longer available.

(2) Falmouth DPW and WQMC presentation 7-29-13 re Draft FCWMP/FEIR/TWMP.

(3) SSWR5.1 analysis

(4) Estimated that if 30% of Falmouth households use composting toilets, the saved fertilizer cost could amount to $10,000.

(5) US EPA Composting Toilets Fact Sheet

- **LINK:** https://www.epa.gov/sites/production/files/2015-06/documents/comp.pdf

(6) EcoSanRes, Toilets That Make Compost, 2007

- **LINK:** http://www.ecosanres.org/pdf_files/ESR-factsheet-13.pdf

(7) Peter Morgan, Toilets That Make Compost, 2007

- **LINK:** http://www.ecosanres.org/pdf_files/ToiletsThatMakeCompost.pdf

(8) SunMar Toilets

- **LINK:** http://www.sun-mar.com/

(9) SanCor Industries Toilets

- **LINK:** http://www.sancor.ca/

(10) Construction costs includes cost for plumbing modifications based on 50% the cost of the toilet.

Toilets: Incinerating

(1) Barnstable County Department of Health and Environment

- **LINK:** http://www.barnstablecountyhealth.org/resources/publications/compendium-of-information-on-alternative-onsite-septic-system-technology/incinerating-toilets

(2) Eco Toilets, Incinerating Toilets As An Alternative To Flushing Toilets

- **LINK:** http://www.eco-toilets.com/incinerating-toilets.php

(3) Nicolet Electric Incinerating Toilets

- **LINK:** http://www.incinolet.com/

(4) Construction costs includes cost for plumbing modifications based on 50% the cost of the toilet.

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Toilets: Packaging

(1) 100% of average nutrient mass excreted per person per day adjusted based on 3 persons / household for Cape Cod.

(2) Construction costs includes cost for plumbing modifications based on 50% the cost of the toilet.

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Toilets: Urine Diverting

(1) Estimated price range for 3 UD systems. Urine Diversion Systems. Lauren Cole et al. Tufts University. Semester Research Project. UEP 0279 Water Resources Policy, P 18.

(2) Earle Barnhart and Hilde Maingay. Let No Waste Go to Waste. Presentation at Howe's House West Tisbury Ma. Nov. 30 2011

- **LINK:** http://mvgazette.com/news/2011/12/01/composting-toilets-pitched-better-sewers-protecting-ponds?k=vg524595282974b&r=1

(3) 80% of average nutrient mass excreted per person per day adjusted based on 3 persons/household for Cape Cod

(4) SSWR5.1

(5) Stockholm Environment Institute - Urine Diversion One Step Towards Sustainable Sanitation - 2006.

- **LINK**: http://www.ecosanres.org/pdf_files/Urine_Diversion_2006-1.pdf

(6) Ecovita West

- **LINK:** http://www.ecovita.net/

(7) Construction costs includes cost for plumbing modifications based on 50% the cost of the toilet.

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Public Facility: Urine Diverting

(1) Estimated price range for 3 UD systems. Urine Diversion Systems. Lauren Cole et al. Tufts University. Semester Research Project. UEP 0279 Water Resources Policy, P 18.

(2) Earle Barnhart and Hilde Maingay. Let No Waste Go to Waste. Presentation at Howe's House West Tisbury Ma. Nov. 30 2011

- **LINK:** http://mvgazette.com/news/2011/12/01/composting-toilets-pitched-better-sewers-protecting-ponds?k=vg524595282974b&r=1

(3) 80% of average nutrient mass excreted per person per day adjusted based on 3 persons/household for Cape Cod

(4) SSWR5.1

(5) Stockholm Environment Institute - Urine Diversion One Step Towards Sustainable Sanitation - 2006.

- **LINK**: http://www.ecosanres.org/pdf_files/Urine_Diversion_2006-1.pdf

(6) Ecovita West

- **LINK:** http://www.ecovita.net/

(7) Construction costs includes cost for plumbing modifications based on 50% the cost of the toilet.

Fertilizer Management

(1) Pleasant Bay Fertilizer Management Plan prepared for the Town of Chatham by Horsley Witten Group, Inc. (2010)

- **LINK:** http://www.pleasantbay.org/wp-content/uploads/101216_FinalReport_10002.pdf

(2) Schueler, Tom et al. 2013. Recommendations of the Expert Panel to Define Removal Rates for Urban Nutrient Management: CBP Approved Final Report

- **LINK:** https://www.chesapeakebay.net/documents/Final_CBP_Approved_Expert_Panel_Report_on_Urban_Nutrient_Management--short.pdf

(3) Reported nutrient removal rates taken from Chesapeake Bay Project report, which reviewed over 200 research studies and reports regarding urban nutrient management programs.

(4) Assumes average 1/2 acre lot size with 1/4 acre landscaped and average Cape Cod rainfall = 45 inches/year of which 25 inches/year to groundwater.

(5) White, Lisabeth M., The Contribution of Lawn Fertilizer to the Nitrogen Loading of Cape Cod Embayments, Thesis, University of Rhode Island, 2003

- **LINK:** https://www.researchgate.net/publication/34254750_The_contribution_of_lawn_fertilizer_to_the_nitrogen_loading_of_Cape_Cod_embayments

(6) Calculation Basis - (a) Each residential lawn approximately 5,000 sqft. (Howes and Ramsey, 2001) ; (b) 8.71 lots per acre; (c) 1.08 lbs/yr per 5,000 sqft residential lawn (Howes and Ramsey, 2001), or 9.41 lbs/acre/yr, or 4.27 kg/acre/yr; (d) Rainfall infiltration for lawns 27.25 inches (Howes and Ramsey, 2001) or 2.27 feet; (e) Cuft rainfall per acre – 98,918; (f) Gallons/acre/yr – 739,900 or 2,027 gallons/acre/year; (g) 2,801,343 liters/acre/yr; (h) Divided 4.27 kg/acre/yr by 2,801,343 liters/acre/year to back into 1.52 mg/L; (i) No construction costs in the matrix at this time; (j) Adjusted annual O&M costs are $20/acre of maintained grounds/year or around $5 per household; and (k) Average Life Cycle Costs are around $115/kg.

Stormwater BMPs

(1) EPA Stormwater BMPs

- **LINK:** https://19january2017snapshot.epa.gov/npdes/national-menu-best-management-practices-bmps-stormwater_.html#edu

(2) California Stormwater Quality Association (CASQA). 2003. Best Management Practices (BMP) Handbook, Municipal

- **LINK:** https://www.casqa.org/resources/bmp-handbooks/municipal-bmp-handbook

(3) Pennsylvania BMP manual

- **LINK:** http://www.stormwaterpa.org/assets/media/BMP_manual/chapter_5/Chapter_5-7-1.pdf

(4) Deriving Reliable Pollutant Removal Rates for Municipal Street Sweeping and Storm Drain Cleanout Programs in the Chesapeake Bay Basin. Center for Watershed Protection. September 2008

- **LINK:** http://www.worldsweeper.com/Street/Studies/CWPStudy/CBStreetSweeping.pdf

(5) Effective street sweeping programs can remove several tons of debris a year from city streets minimizing pollutants, including sediment, debris, trash , road salt and trace metals, in stormwater runoff : (a) Could quantify effect of street sweeping by maintaining logs of the number of curb miles swept and the amount of waste collected ; (b) A study conducted by the Center for Watershed Protection in the Chesapeake Bay Basin indicated that pollutant removal rates for street sweeping and municipal drain cleanout programs can range between 9-31% (TS), 3-7% (TP), and 3-7% (TN); (c) Land use planning: Minimize overall disturbance at individual lot levels as well as construction sites (TSS reduction 40%); and (d) C reduction and control: Minimize pavement by using alternative road layouts, restricting on-street parking, minimizing cul-de-sac radii , and using permeable pavers. A preventative measure for TSS, TP and NO3.

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(6) Maryland Guidance street sweeping typically shows: (a) a 5%TN, 6%TP, and 25% TSS removal when sweeping occurs once every two weeks; (b) Impervious surface elimination can significantly reduce nutrient loads; (c) Converting from impervious to grassed pervious has been shown to reduce TN by 13%, TP by 72%, and TSS by 84%; (d) Converting from impervious to forest has been shown to reduce TN by 71%, TP by 94%, and TSS by 93%; and (e) Similar potential exists for strict redevelopment standards which require introduction of stormwater management to existing impervious cover which is being redeveloped.

(7) Tree planting or reforestation also has significant potential. Converting from grassed pervious to forest can reduce TN by 66%, TP by 77%, and TSS by 50%.

(8) Stream restoration is also a potentially very important strategy. In the Chesapeake Region, new planning guidance for stream restoration removal rates has been issued. This research suggests TN removal of 0.2 lbs per linear foot, TP removal of 0.068 lbs per linear foot, and TSS removal of 310 lbs per linear foot.

- **LINK:** http://chesapeakestormwater.net/bay-stormwater/baywide-stormwater-policy/urban-stormwater-workgroup/urban-stream-restoration/

(9) Similar potential is available for shoreline stabilization. Some guidance estimates these removal rates at 0.16 lbs TN/linear foot, 0.11 lbs TP/linear foot, and 451 lbs TSS/linear foot.

(10) Fertilizer management is also potentially a critical strategy for controlling the discharge of nutrients in stormwater. Recent guidance suggests nutrient management can reduce nutrient loading in urban stormwater by 17% for TN and 22% for TP.

(11) Highly feasible to implement an O&M plan and public outreach/education programs; however, dependent upon funding. Land use planning and IC reduction and control can be implemented through local boards, commissions and ordinances.

(11) Costs not included as regulatory agencies require stormwater BMPs to be implemented by the municipalities.

(12) Treatment level for typical stormwater BMPs may not meet the requirements for N and P reduction. Enhancements beyond stormwater MS4 should be considered on a case by case basis.

(13) Calculation Basis - (a) Technology metric is a curb mile; (b) Assumed average road width 30 ft.; (c) Square feet in curb mile approx. 158,400 sq ft.; (d) Rainfall

runoff approx. 40 inches per year (Howes and Ramsey, 2001); (e) Cubic feet of rainfall per road mile – 528,000; (f) Gallons per curb mile/year – 3,949,440 (10,820 gal/day); (g) Liters per curb mile/year – 14,952,960 liters/acre/year; (h) Road runoff nitrogen concentration mg/L 1.5 mg/L (Howes and Ramsey, 2001); (i) 22.4 kg/curb mile/year; and (j) 11.4 kg/curb mile/year if removed of 50% removed.

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Remediation of Existing Development

(1) In Person Interview: Scott Horsley, Horsley Witten, http://www.horsleywitten.com/

(2) This technology should be encouraged, but would be difficult to quantify potential nitrogen reductions without conducting site specific analyses.

Compact and Open Space Development

(1) This technology should be encouraged, but would be difficult to quantify potential nitrogen reductions without conducting site specific analyses.

Transfer of Development Rights

(1) Rick Pruetz, Beyond Takings and Givings, 2003.

(2) Massachusetts Smart Growth / Smart Energy Toolkit.

- **LINK:** http://www.mass.gov/envir/smart_growth_toolkit/pages/mod-tdr.html

(3) This technology should be encouraged, but would be difficult to quantify potential nitrogen reductions without identifying specific preservation areas (sending areas) and specific development districts (receiving areas).

Inlet / Culvert Widening

(1) Bournes Pond.

(2) Actual costs will be site specific.

(3) In general, increasing the capacity of bridges and culverts is a good way to increase upstream and downstream water quality and enhance upstream habitats. However, care must be taken in the design so as not to adversely affect upstream and downstream habitats and or negatively impact upstream or downstream properties and structures. The design requires detailed modeling (preferably 2-dimensional hydrodynamic modeling) to quantify the potential upstream and downstream impacts.

(4) Calculation Basis - Costs based on Pond Dredging which has a stable nutrient load and therefore P (or N) reduction can be calculated; (b) Dredging in estuary is difficult as N load varies as well as flushing of the estuary; (c) costs change based on depth of excavation and may involve removing and replacing infrastructure; and (d) requires modeling to identify nutrient reduction and costs.

Coastal Habitat Restoration

(1) See References - Aquaculture

Wild Oyster Bed Maintenance

No References

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Floating Constructed Wetlands

(1) Communications with Robert Crook of Floating Islands International.

- **LINK:** http://www.floatingislandinternational.com/

(2) Project Descriptions at Floating Islands International

(3) Floating Islands West LLC

- **LINK:** http://www.floatingislandswest.com/

Pond and Estuary Circulators

(1) Medoraco Corp.

- **LINK:** http://www.medoraco.com/

Surface Water Remediation Wetlands

(1) Average Removal Rate from Kadlec and Knight. Treatment Wetlands, 2009 (P 419).

- **LINK:** https://books.google.com/books?id=hPDqfNRMH6wC&printsec=frontcover&dq=Kadlec+and+Knight.+Treatment+Wetlands&hl=en&sa=X&ved=0ahUKEwiZ5PH49OHYAhUMOawKHXcZACYQ6AEIJzAA#v=onepage&q=Kadlec%20and%20Knight.%20Treatment%20Wetlands&f=false

(2) Average treatment capacity of two remediation wetland projects (Des Plaines River Wetland Demonstration Project and Richland Chambers Wetland.

- **LINK:** https://nepis.epa.gov/Exe/ZyNET.exe/2000475J.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1991+Thru+1994&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C91thru94%5CTxt%5C00000007%5C2000475J.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

(3) Range of wetland costs adjusted to 2012 dollars from Constructed Wetlands Treatment of Municipal Wastewaters. EPA.1999. (P 132-133.)

- **LINK:** https://nepis.epa.gov/Exe/ZyNET.exe/30004TBD.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1995+Thru+1999&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C95thru99%5CTxt%5C00000016%5C30004TBD.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

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(4) Range of O&M values adjusted for inflation From Jim Kreissl. Constructed Wetlands Treatment for Nutrient Treatment for Nutrient Reduction. Presentation at POTW Nutrient Reduction and Efficiency Workshop, 2008.

(5) Kadlec and Knight. Treatment Wetlands (P 463).

- **LINK:** https://books.google.com/books?id=hPDqfNRMH6wC&printsec=frontcover&dq=Kadlec+and+Knight.+Treatment+Wetlands&hl=en&sa=X&ved=0ahUKEwiZ5PH49OHYAhUMOawKHXcZACYQ6AEIJzAA#v=onepage&q=Kadlec%20and%20Knight.%20Treatment%20Wetlands&f=false

(6) 1 acre of SSF CTW will treat 50-75 homes/acre Total Nitrogen at 330 gpd. Assumptions: Q= 330 gpd (1.25 mg/l); Ci = 20 mg/l; Ce = 5 mg/l (TN), k (areal removal rate constant): 4-15 m/yr. C* = 0 mg/l (background). Equates to 0.015 to 0.025 acres/330 gpd.

(7) These are Constructed Treatment Wetland Cells often designed as FWS cells constructed in an upland location, lined and sized accordingly based on design flow to manage (Q), influent pollutant concentration(Ci), and target goal for effluent concentration (Ce) along with a decay constant (k) (areal rate constant). Much of the information presented above for FWS wetlands is applicable here, direct gravity discharge is preferred over pumping and many pollutants can be managed with these systems including nutrients (N, P), TSS, BOD, pH, suspended metals, TPH and pathogens. These systems can often be integrated as tertiary polishing units depending on the pollutant for existing surface waters to be directed through. If a system like this is integrated with an existing impaired surface water, flood management/mitigation needs to be fully evaluated. There are some passive benefits of these systems including creating aquatic habitat for a wide range of fish, amphibians and other wildlife.

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Chemical Treatment of Ponds

(1) Freeman and Everhart (1971) - constant flow bioassays, to determine that concentrations of dissolved aluminum below 52 g Al/L had no obvious effect on rainbow trout. Similar results have been observed for salmon.

- **LINK:** https://www.researchgate.net/publication/254328157_Toxicity_of_Aluminum_Hydroxide_Complexes_in_Neutral_and_Basic_Media_to_Rainbow_Trout

(2) Cooke, et al (1978) - Adopted 50 mg Al/L as a safe upper limit for post-treatment dissolved aluminum concentrations.

(3) Kennedy and Cooke (1982) - Indicate that dissolved aluminum concentrations, regardless of dose, would remain below 50 g Al/L in the pH range 5.5 to 9.0, a dose producing post-treatment pH in this range could also be considered environmentally safe with respect to aluminum toxicity.

- **LINK:** http://www.phosclear.com/downloads/Control%20of%20Lake%20PO4%20with%20Alum.pdf

(4) March 2003 - Wisconsin Department of Natural Resources, Alum Treatments to Control Phosphorus In Lakes.

- **LINK**: http://www.littlesaint.org/misc_documents/alum_phosphorous_control_dnr.pdf

(5) AECOM (2009) - Treatment Summary for Phosphors Inactivation in Long Pond, Brewster and Harwich MA. Concentration from the sediment entering the water column is variable. Study of Long Pond in Harwich/Brewster showed concentrations of available phosphorus within the sediment ranged from 0.6 to 4.6 g/m2 based on year 2000 data for the upper 4 cm of sediment. More recent data collected by the Town of Brewster indicates a very similar range of 0.7 to 4.5 g/m2. A summer release of 0.6 g/m2 with only 10% reaching the epilimnion could raise the phosphorus concentration by more than 0.02 mg/L and support algal blooms.405 kg/yr (65%) to the upper waters out of a total load of between 606 and 651 kg/yr.

- **LINK:** http://brewster-ma.gov/files/longalum.pdf

(6) AECOM 2009 - Minneapolis MN Parks and Recreation Board

Title 5 Septic System Replacement (Base Line Condition)

(1) Barnstable County Cost Report, April 2010

- **LINK:** http://www.ccwpc.org/index.php/component/content/article/36-wastewater-reports/78-comparison-of-costs-for-wastewater-management-systems-applicable-to-cape-cod

(2) Low end reflects only a basic system with no new grading or pump required for raised leaching field. Many replacement systems that require upgrade to meet current Title 5 standards (1994 vs 1978) may require > GW offset or other site restriction that demands pumped effluent to leaching field. New septic tanks should include effluent Tee filter to minimize solids carry-over to field.

(3) See Note 12.

> **NOTE 12.** The Nitrogen Load Reduction Calculator assumes a baseline input of 26.25 mg/L. The input is based on the Massachusetts Estuaries Program (MEP) assumption that existing nitrogen load from existing septic system wastewater systems to the groundwater is 26.25 mg/L. This 26.25 mg/L assumes nitrogen reduction from the existing septic systems as well as treatment in the subsurface soils between the septic system discharge and the water table. In other words, the existing nitrogen load to the watershed is 26.25 mg/L from the existing septic systems. The net reduction from a specific technology would be the decreased nitrogen load achieved by installing and operating the selected technology. The Nitrogen Load Reduction Calculator is used to estimate the cost per pound of nitrogen reduced from the watershed in order to compare the cost-effectiveness of the technologies but not to calculate a project cost for the technology.

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Innovative/Alternative (I/A) Systems

(1) Barnstable County Cost Report, April 2010

- **LINK:** http://www.ccwpc.org/index.php/component/content/article/36-wastewater-reports/78-comparison-of-costs-for-wastewater-management-systems-applicable-to-cape-cod

(2) The MassDEP standards for operation and maintenance of I/A systems

- **LINK:** http://www.mass.gov/eea/agencies/massdep/water/wastewater/maintaining-and-repairing-innovative-alternative-system.html

(3) Approved I/A systems are provided at the following MassDEP website

- **LINK:** http://www.mass.gov/eea/agencies/massdep/water/wastewater/summary-of-innovative-alternative-technologies-approved.html

Innovative/Alternative (I/A) Enhanced Systems

(1) Barnstable County Cost Report, April 2010

- **LINK**: http://www.ccwpc.org/index.php/component/content/article/36-wastewater-reports/78-comparison-of-costs-for-wastewater-management-systems-applicable-to-cape-cod

(2) The MassDEP standards for operation and maintenance of I/A systems

- **LINK**: http://www.mass.gov/eea/agencies/massdep/water/wastewater/maintaining-and-repairing-innovative-alternative-system.html

(3) Approved I/A systems are provided at the following MassDEP website

- **LINK**: http://www.mass.gov/eea/agencies/massdep/water/wastewater/summary-of-innovative-alternative-technologies-approved.html

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Treatment Systems

CLUSTER TREATMENT SYSTEM - SINGLE-STAGE

CLUSTER TREATMENT SYSTEM - TWO-STAGE

CONVENTIONAL TREATMENT

ADVANCED TREATMENT

SATELLITE TREATMENT

SATELLITE TREATMENT - ENHANCED

(1) Barnstable County Cost Report, April 2010

- **LINK:** http://www.ccwpc.org/index.php/component/content/article/36-wastewater-reports/78-comparison-of-costs-for-wastewater-management-systems-applicable-to-cape-cod