Tighe&Bond

15-0173-002
September 21, 2021

Mr. Michael Conklin
Director of Environmental Affairs
Town of Wilton
141 Danbury Road,
Wilton, CT 06897

Re: **Inland Wetlands Commission**
Department of Public Works/Town Engineer Comments
WET#2714 (S) – FDSPIN 141 DR LLC
141 Danbury Road, Wilton, CT (Accessor's Map 70, Lot 2)

Dear Mr. Conklin:

Thank you for the opportunity to address the DPW review comments prepared by Frank Smeriglio, dated 9/9/2021. The following summarizes their comments in *italic* and our responses in **bold** text. Should you require additional information or materials, please let us know.

Staff Comments:

1. *"It shall be noted that since the property abuts Route 7, the State DOT shall review the design plans as it relates to their roadway."*

   Response: So noted. This review with the State is already underway and Tighe & Bond will address any comments from their review once received.

2. *"For record tracking purposes, please provide the following:*
   a. *Existing Pervious Surface Area (sqft)*
   b. *Existing impervious surface area directly connected to the watercourse (sqft)*
   c. *Existing impervious surface area disconnected from the watercourse (sqft).*
   d. *Proposed pervious surface area (sqft)*
   e. *Proposed Impervious surface area disconnected from the watercourse (sqft)*
   f. *Proposed impervious area directly connected to the watercourse (sqft)."*

   Response: Requested areas are as follows:
   a. 83,287 sqft
   b. 112,908 sqft
   c. 8,276 sqft
   d. 72,484 sqft
   e. 119,834 sqft
   f. 10,237 sqft

3. *"Other comments relating to site plan details, sewer system, etc shall be reviewed as part of the Planning & Zoning approval process."*

   Response: So noted.

If you have any questions, please feel free to contact us at 860-852-5219.

Very truly yours,

TIGHE & BOND, INC.

Erik W. Lindquist, P.E., LEED AP
Senior Project Manager

John W. Block, P.E., L.S.
Senior Vice President

Tighe&Bond

15-0173-002
October 8, 2021

Mr. Michael Conklin
Director of Environmental Affairs
Town of Wilton
141 Danbury Road,
Wilton, CT 06897

Re: **Inland Wetlands Commission**
Third Party Review Comments
WET#2714 (S) – FDSPIN 141 DR LLC
141 Danbury Road, Wilton, CT (Accessor's Map 70, Lot 2)

Dear Mr. Conklin:

Thank you for the opportunity to address the Third-Party review comments prepared by Alan Pilch at ALP Engineering & Landscape Architecture, PLLC, dated 9/2/2021. The following summarizes their comments in *italic* and our responses in **bold** text. Should you require additional information or materials, please let us know.

Staff Comments:

1. *"The Engineering Report provides information on the results of soil borings, which were conducted in 1992. With regards to the testing, we recommend that the developer provide the IWC with a map showing the location of borings. Furthermore, we recommend that there be at least two percolation tests performed in the footprint of each of the four stormwater management practices being proposed. This information is needed at this time, rather than prior to the completion of construction documents, in order to assess how well the proposed stormwater management practices will function, and whether site design changes will be needed. We recommend that the percolation test hole be dug so that the bottom of the percolation test hole is at least one (1) foot below the elevation of the bottom of the practice."*

   Response: Deep test holes and percolation testing were performed on site on September 20, 2021. Per our phone discussion, six (6) test holes were dug in total, two (2) were performed in the location of each of the two porous pavement systems, and one (1) in each of the infiltration systems. Material on-site was coarse sandy material, which provided for good percolation test results in all but one area (TP-4). Based on your concerns with the suitability of the testing performed at TP-4, we have proposed eliminating the porous pavement in this area and replacing it with standard bituminous pavement. In order to satisfy the water quality requirements for the site, the adjacent CB has been revised to an inlet water quality structure to treat the surface runoff. Section 7.2 of the CT DEEP Stormwater Quality Manual notes that infiltration practices shall be used where practical and that high groundwater, ledge, and poor soil conditions are acceptable constraints to limit the use of infiltration on subject sites. Reducing the amount of infiltration did slightly modify the peak rates of runoff discharging to the Norwalk River, but they are still considerably lower than the existing runoff currently being experienced

on site. The revised plans and calculations associated with these revisions have been provided for your review along with the product information for the water quality structures to document its ability to remove 80% of total suspended solids (TSS). The table below summarizes our findings for flow reduction from the site:

Table 1: Revised Design Peak Discharges to Norwalk River (CFS)

	2 YR	10 YR	25 YR	50 YR	100 YR
Q_{pk} - Existing	7.662	13.50	17.25	20.05	23.05
Q_{pk} - Proposed	1.976	7.294	11.77	14.82	18.74
Reduction in Peak Flow	**74.2%**	**46.0%**	**31.8%**	**26.1%**	**18.7%**

2. *"The Soil Survey of the State of Connecticut notes two soil types on the property, Rippowam fine sandy loam and Urban Land. Rippowam soils are nearly level and occur in flood plains. Urban Land soils are 'so variable that on-site investigation is required to determine the suitability of the proposed use'. Hence, the need for on-site soils testing. The Rippowam soils in the USDA mapping extend from the Norwalk River to about two-thirds of the distance along the northern property line. The prior development of the subject property has resulted in modification of the soil profile of what likely was Rippowam soils into what is now classified as Urban Land. The Soils Survey notes the Rippowam fine sandy loam features a depth to a seasonal water table 0 to 18", and this shallow dept to the water table can occur in all parts of the year. It can also be greater than 6-feet during all months of the year. The concern here is the proposed stormwater management practices will function as intended only if the groundwater table is at least 3-feet below the bottom of the practice per the Connecticut Stormwater Quality Manual. If precipitation events during a season result in a high seasonal water table, then the proposed stormwater management practices will not function as intended since they or the soils below the practices would be saturated with water. Given the Rippowam fine sandy loam soils are subject to this high seasonal water table and it can occur throughout the year, it calls into question the ability of these practices to provide the peak rate attenuation and the water quality improvement, and contribute to additional flooding in the Norwalk River."*

   Response: Deep test holes were performed on site as noted in the response to Comment #1. All test holes were dug approximately 7 to 7.5-feet deep and had no observance of groundwater or redoximorphic soil features (mottling). This is consistent with the historic monitoring well data and the more current readings provided by GZA, which observed groundwater surface elevations down approximately 8.5 to 9-feet. Since our infiltration practices are all set at elevation 141.0, the groundwater surface elevation will be at least 2-feet below, and in some cases over 3-feet below the bottom of our system. The additional field deep tests confirm that there is adequate separation distance from ground water for the proposed infiltration practices and that they will function as designed.

3. *"We question the Tc flow path in the Existing Condition Watershed Map. Flow paths do not run perpendicular to the contour EX-WS-01. For EX-WS-02, the sheet flow segment of flow, which is calculated to be 130 feet, appears to be much shorter before its conversion to shallow concentrated flow. Furthermore, using a sheet flow length of over 100-ft in the modeling methodology is not permitted unless the flow is across a planar segment of pavement. The effect of modeling of excessive*

or incorrect sheet flow lengths will be to increase the time of concentration with the resultant decrease in the peak rates of runoff. Using the shorter lengths of sheet flow will result in more accurate time of concentration calculation, and a higher existing condition peak rate of runoff.".

Response: The modifications being requested would only serve to raise the calculated flow for the existing condition thereby reducing the need for more extensive proposed stormwater management measures. The Tc paths and assumptions used were intended to be more conservative and therefore our proposed system has been designed to further reduce runoff below the more conservative estimates for the existing condition.

4. *"We also question the Tc flow path in Figure WM-01, Proposed Watershed Map. Please provide a full-size sheet of the Existing and Proposed Watershed Maps showing the existing and future condition site grading, respectively, for review."*

   Response: Based on our phone conversation on September 14, 2021, the need for additional mapping is not required. As noted above and during our prior discussions, the requested revisions to the Tc flow paths for existing and proposed conditions will not have a significant impact on the design of the proposed stormwater management system if revised and can remain as shown.

5. *"Given that the Northern Porous Pavement facility will be placed where the grade drops over 2-feet, and for the southern porous pavement facility the grade drop is proposed to be about 3.7 feet, show on the plans the locations where the compacted clay and silt berms will be placed in the plans, or indicate that the porous pavement sections will be benched and a berm placed at each drop in the bench to promote infiltration. The water quality volume calculations and the porous pavement section detail need to take into account the grade change across the porous pavement facilities."*

   Response: The porous pavement is being constructed on a slight variable slope that ranges between 1.8% and 2.5%. Industry standards consider porous pavement a suitable BMP measure on slopes ranging from 0% to 5%. Since the porous pavement is located within the floodplain, we are limited on how much we can alter existing grades, but the proposed slope falls well within the typical application ranges. The bottom of the system is designed to mirror the surface slope condition to reduce the amount of disturbance to native soils and the subsequent volume of earthwork being generated on site. A series of 12-inch berms are being proposed within the reservoir course of the porous pavement section that will be placed at 20 to 25-foot increments perpendicular to the slope in order to check water and promote infiltration. These locations have not been shown on the plans as they will be determined based on field conditions to maximize their effectiveness. Benching the system will operate in a similar fashion and still require these berms; however, it will require additional excavation at each tier as the bench extends into the native grade. We can modify the system to show the bench if desired; however, we ask the third-party review engineer to reconsider this recommended revision and support the current design to limit the disturbance of native soils on site while still promoting infiltration of the proposed water quality volume.

6. *"Show the locations of the proposed 6" underdrains with the ASTM No. 2 stone reservoir course on the Stormwater Management Plan. Where will the runoff from these underdrains be conveyed. Show he location of the discharge of these underdrain pipes on the Stormwater Management Plan."*

   Response: Sheet C-301 currently shows the locations of the perimeter underdrains for the porous pavement system and their routing. Additional drain lines that 'T' off these main drains will likely be added during construction based on field conditions and the final locations of the proposed berms noted in the response to Comment #5.

7. *"Provide a section through the northern and southern porous pavement facilities which show the location of the drainage pipes from infiltration system No.1 and No. 2 through the systems. Will these drainage pipes from the infiltration systems impact the perforated underdrain pipes?"*

   Response: As seen on sheet C-301, the underdrains have been located to avoid conflicts with the stormwater management system. Any additional drains added would also be placed to avoid these crossings.

8. *"The western ends of the Northern and Southern porous pavement facilities are very close to the mapped Rippowam fine sandy loam soils. Provide information that will demonstrate that the porous pavement facilities will not be impacted by a high seasonal groundwater table, which would reduce the volume available for peak rate attenuation and prevent the treatment of the water quality volume since treatment of runoff pollutants is dependent on providing 3 feet of unsaturated soil below the bottom of the No.2 stone reservoir course.*

   Response: Please see response to Comment #2.

9. *"The flow path for CB-01 and CB-01A do not appear to correctly represent the actual sheet flow and shallow concentrated flow segments and need to be revised. Flow paths do not run perpendicular to the contour for EX-WS-01. For EX-WS-02, the sheet flow segment of flow, which is calculated to be 130-feet, appears to be much shorter before its converted to shallow concentrated flow. Furthermore, using a sheet flow length of over 100-ft in the modeling methodology is not permitted unless the flow is across a planar segment of pavement."*

   Response: See the provided responses to Comments #3 and #4.

10. *"The Engineering Report Stage/Storage Table for the North and South Infiltration Systems provide storage of runoff commencing at elevation 141.0 feet yet the details on sheet C-606 show a stone base elevation of 142.0 feet. This needs to be rectified to be consistent. Show on the section through the infiltration system the inflow pipes into the chambers."*

    Response: We do not see this conflict on the drawings; however, the initial submission from June 7 did have a typo that was corrected on the revised July 15 resubmission. The bottom of the two systems is currently proposed to be at elevation 141.0 and all details and calculations should reflect this.

11. *"Provide pipe flow calculations to demonstrate that the proposed storm drainage system will be able to convey the anticipated flows. For one example, the rip rap*

apron discharge in Appendix I is designed to convey a flow rate of 9.14 CFS. However, the hydrograph return period recap for the total site combined flows shows a peak rate of flow of 10.69 CFS for the 25-year storm and 17.35 CFS for the 100-year storm, in excess of the design flow."

Response: The revised Storm Sewer Tabulation for verifying the pipe flow sizing has been provided with these responses for your review. The riprap apron sizing has also been revised with these responses based on the updated flow information from the Hydrograph Return Period Recap summary report. The current design flow for the 25-year peak storm event is calculated to be 10.14 CFS and the detail on sheet C-605 was updated to reflect the revised flow information. The storm drainage system was also sized to convey the 25-year storm per the Town of Wilton requirements. It is important to note the discharge line out to the river will have a check valve to prevent the Norwalk River from flowing back into our system. The tailwater elevation in the Norwalk River during flooding events will result in a similar hydraulic grade line building up within the proposed piped drainage system. In the event the system is submerged and the river elevation rises to the parking area (which didn't happen during the most recent significant storm event on 9/1/21 through 9/2/21, Hurricane Ida), the site has been designed to still maintain sheet flow runoff out from the proposed parking areas and towards the river.

If you have any questions, please feel free to contact us at 860-852-5219.

Very truly yours,

TIGHE & BOND, INC.

Erik W. Lindquist, P.E., LEED AP
Senior Project Manager

John W. Block, P.E., L.S.
Senior Vice President

MEMORANDUM

TO: Wilton Inland Wetland Commission

CC: Michael Conklin

FROM: Carmody Torrance Sandak & Hennessey, LLC, attorney for the applicant FDSPIN 141 DR LLC

DATE: October 8. 2021

RE: Response to Commission Inquiry dated September 17, 2021.

Connecticut General Statutes §22a-36 provides the purpose of the inland wetlands and watercourses legislation. Significantly, the stated value of this important natural resource is not limited to wildlife habitat and biological improvements. Rather, the statute lists a number of benefits and specifically recognizes the value in *"protecting the quality of wetlands and watercourses for their conservation, economic, aesthetic, recreational and other public and private uses."* [1] It goes on to note that the intention of the Inland Wetlands and Watercourses Act is to *"<u>balance</u> the need for the economic growth of the state and the use of its land with the need to protect its environment and ecology in order to forever guarantee to the people of the state, the safety of such natural resources for their <u>benefit and enjoyment</u> and for the benefit and enjoyment*

1 C.G.S. §22a-36 ("The inland wetlands and watercourses of the state of Connecticut are an indispensable and irreplaceable but fragile natural resource with which the citizens of the state have been endowed. The wetlands and watercourses are an interrelated web of nature essential to an adequate supply of surface and underground water; to hydrological stability and control of flooding and erosion; to the recharging and purification of groundwater; and to the existence of many forms of animal, aquatic and plant life. Many inland wetlands and watercourses have been destroyed or are in danger of destruction because of unregulated use by reason of the deposition, filling or removal of material, the diversion or obstruction of water flow, the erection of structures and other uses, all of which have despoiled, polluted and eliminated wetlands and watercourses. Such unregulated activity has had, and will continue to have, a significant, adverse impact on the environment and ecology of the state of Connecticut and has and will continue to imperil the quality of the environment thus adversely affecting the ecological, scenic, historic and recreational values and benefits of the state for its citizens now and forever more. The preservation and protection of the wetlands and watercourses from random, unnecessary, undesirable and unregulated uses, disturbance or destruction is in the public interest and is essential to the health, welfare and safety of the citizens of the state. It is, therefore, the purpose of sections 22a-36 to 22a-45, inclusive, to protect the citizens of the state by making provisions for the protection, preservation, maintenance and use of the inland wetlands and watercourses by minimizing their disturbance and pollution; maintaining and improving water quality in accordance with the highest standards set by federal, state or local authority; preventing damage from erosion, turbidity or siltation; preventing loss of fish and other beneficial aquatic organisms, wildlife and vegetation and the destruction of the natural habitats thereof; deterring and inhibiting the danger of flood and pollution; protecting the quality of wetlands and watercourses for their conservation, economic, aesthetic, recreational and other public and private uses and values; and protecting the state's potable fresh water supplies from the dangers of drought, overdraft, pollution, misuse and mismanagement by providing an orderly process to balance the need for the economic growth of the state and the use of its land with the need to protect its environment and ecology in order to forever guarantee to the people of the state, the safety of such natural resources for their benefit and enjoyment and for the benefit and enjoyment of generations yet unborn.")

of generations yet unborn."[1]

It is this balanced approach that led to the concept of upland review areas. As you know, these are areas outside of the wetlands or watercourses that can be designated by the local municipality as part of the "regulated area" for purposes of review. However, regulation in these areas is limited to activities that are likely to impact or affect the wetlands and watercourses themselves.[2] Thus, while the upland review area is a jurisdictional area, it is not a buffer of no disturbance.[3] Conducting a "regulated activity" in a "regulated area" requires a permit from the Inland Wetlands Commission of the Town of Wilton (the "**Commission**"), but activity within said regulated area is not strictly prohibited, allowing the Commission to approve a variety of Regulated Activity Applications.[4]

When evaluating potential adverse impacts on the wetlands or watercourses, the Commission must be guided by the factors found in Section 10.3 of the Inland Wetlands and Watercourse Regulations for the Town of Wilton, Connecticut. The proposal's adherence to these standards and criteria was included in the project narrative accompanying the application materials and is attached hereto for ease of reference.

In terms of the stormwater management system specifically, water quality for stormwater is based on initial runoff volumes and not on rainfall frequency or intensity. The basis for this is that the initial 'first flush' of runoff is what carries off debris, sediment, and other pollutants that collect on impervious surface areas. The stormwater management system is designed to capture and fully infiltrate this initial volume to significantly enhance runoff *quality* discharging from the site. Once the first flush is retained, the subsequent runoff is able to bypass the storage volumes since these flows are considerably cleaner. As noted at the hearing, it is not practical or feasible to design a stormwater management system to retain the water volume of a 100-year storm, notwithstanding the fact that these storms are likely to become more frequent. Flooding will occur which is why the building has been specifically designed to withstand flood waters, as required by the flood zone regulations.

Furthermore, thermal pollution is mitigated in the same way. Once the rain has fallen for a few minutes (the first flush), the pavement is cooled and further runoff is no longer warmed on impervious surfaces. The heated water from the first flush is retained with the sediment and other pollutants within the subsurface infiltration system where it is cooled and recharged into

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2 C.G.S. §22a-42a(f) ("If a municipal inland wetlands agency regulates activities within areas around wetlands or watercourses, such regulation shall (1) be in accordance with the provisions of the inland wetlands regulations adopted by such agency related to application for, and approval of, activities to be conducted in wetlands or watercourses and (2) apply only to those activities which are likely to impact or affect wetlands or watercourses.")
3 The Commission Inquiry included materials from the CTDEEP Inland Fisheries Division that describe a 100' undisturbed buffer policy from 1991 that was never adopted or codified by state statute. Rather, in 1997, CTDEEP adopted guidelines for "Upland Review Area Regulations" which established a jurisdictional area, not a buffer of no disturbance.
4 For example, the Commission recently approved of a significant activity in the regulated area on property located at 77 Danbury Road for ASML (WET#2307 & WET#2659(S)).

the ground.

Lastly, the Applicant notes that, while impervious surface will modestly increase on the site overall (from 63.28% to 67.80%), this is only because the Zoning Regulations do not currently account for porous pavement which provides many of the same benefits as natural pervious surfaces from an engineering perspective. If the .56 acres of pervious pavement were deducted from the impervious surface calculation, the total impervious would actually decrease to approximately 55%.

The noted general environmental concerns articulated in the September 17th inquiry are applicable to any regulated activity in any regulated area adjacent to the Norwalk River.[5] Thus, the Applicant submits that there is no evidence to suggest that the proposed regulated activity, namely the replacement of asphalt with plantings and pervious pavement in the upland review area and the discharge of treated stormwater within the Norwalk River, will negatively impact or affect the wetlands or watercourse on site. However, as detailed in the letter from Environmental Land Solutions dated September 21, 2021 and attached hereto, there is substantial evidence confirming that the proposed restoration will significantly improve water quality and wildlife habitat on and around the site, and perhaps as importantly, provide a place of respite for the residents living in the building.

For all the reasons provided above, the Applicant submits that the proposed redevelopment plan will not have an adverse impact on the wetlands or watercourse and same should be approved.

5 *River Bend Associates, Inc. v. Conservation & Inland Wetlands Commission*, 269 Conn. 57, 71 ("Evidence of general environmental impacts, mere speculation, or general concerns do not qualify as substantial evidence [of likely adverse impact on the wetlands or watercourse]")

<u>Project Narrative</u>

I. Background

FDSPIN 141 DR LLC (the **"Applicant"**) is the contract purchaser of the property located at 141 Danbury Road, Wilton, Connecticut (the **"Property"**). The Property consists of approximately 4.28+/- acres on the westerly side of Danbury Road and is designated as Tax Lot 2 on Map 70 in a DE-5 Design Enterprise District. The Property is adjacent to the Norwalk River. The Applicant seeks to redevelop the Property with a multifamily residential building and associated landscape and site improvements. Because these site enhancements will partially take place in the regulated area, the Applicant is seeking approval of an Application for a Significant Regulated Activity from the Inland Wetlands Commission (the **"Commission"**).

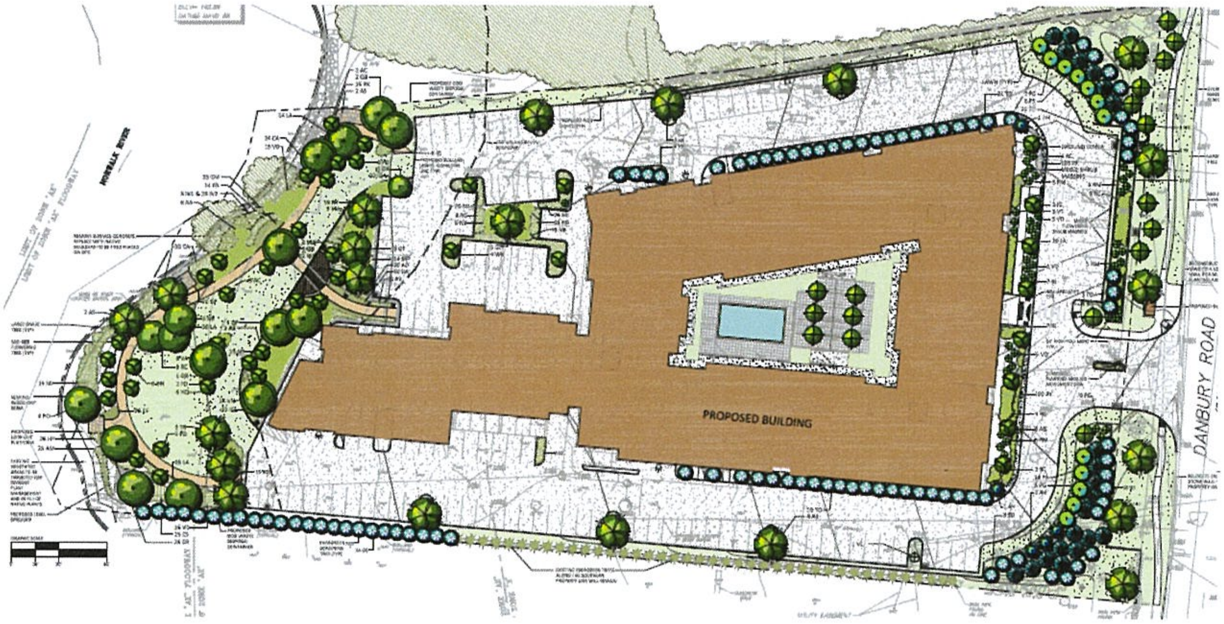
The Property is currently improved with a warehouse style office building and a large surface parking lot extending up to the river's edge. These impervious improvements currently cover 63% of the Property, and stormwater currently sheet flows over the site directly into the river without any water quality treatment. The width of the riparian buffer adjacent to the river varies from 0' to 35'+/- across the westerly portion of the Property. The Property, and existing improvements located thereon, are depicted in the aerial photograph below.[1]

II. Proposal

[1] Aerial photograph of the Property obtained from the Wilton GIS website.

{S7311830}

The enclosed application is in furtherance of the redevelopment of the Property that, if approved, will allow the Applicant to replace the existing structure and parking with a new multi-family residential building accompanied by dense landscaping throughout the Property, including the westerly portion of the site along the Norwalk River.



As seen in the above rendered Landscape Plan, the Applicant proposes transforming 85% of the area within the Regulated Area (approximately 25,020+/- sf) from a paved parking area to a private landscaped, recreational area. This passive, recreational space will consist of native trees, shrubs and perennials. Because much of the site is in the Flood Zone, the building will be raised with parking beneath it. Aside from building columns (approximately 315+/- sf), the building itself is located entirely outside of the Regulated Area and site improvements are no closer than 66' to the Norwalk River. Although not visible in the image above, porous pavers will be utilized on all parking surfaces within 200' of the Norwalk River, further facilitating the reduction of runoff by infiltrating rainwater and melting snow. Material excavated onsite will be utilized as fill, and additional pavement subbase will be incorporated on an as-needed basis.

Work within the Regulated Area is intended to restore and enhance the natural characteristics of the Property and significantly improve water quality on the site, and to provide outdoor, passive recreation space for the residents. While no adverse impacts are anticipated, Best Management Practices (BMPs) as described in the enclosed Engineering Report and plans are incorporated to avoid and minimize potential adverse environmental impacts.

III. Compliance with Standards & Criteria For Decision

The proposal is compliant with the standards of Section 10.3 of the Inland Wetlands and Watercourses Regulations for the Town of Wilton (the "Regulations") as follows:

In carrying out the purposes and policies of sections 22a-36 to 22a-45, inclusive, of the Connecticut General Statutes, including matters relating to regulating, licensing and enforcing of the provisions thereof, the Commission shall consider all relevant facts and circumstances in making its decision on any application for a permit, including but not limited to the following:

> a) *Impacts of the proposed regulated activity on wetlands or watercourses outside the area for which the activity is proposed and future activities associated with, or reasonably related to, the proposed regulated activity which are made inevitable by the proposed regulated activity and which may have an impact on wetlands or watercourses.*

All of the work proposed within the Regulated Area is intended to restore and expand the function of the Norwalk River's riparian buffer, improve water quality and provide wildlife habitat, while simultaneously providing recreation space for residents. As such, no impacts on wetlands or watercourses outside the area for which the activity is proposed are anticipated. Similarly, future activities associated with, or reasonably related to the proposed regulated activity will be primarily comprised of Wilton residents enjoying the landscaped areas proposed by the Applicant. No direct disturbance is proposed. Therefore, no adverse impact on wetlands or watercourses are anticipated. In fact, improvements to the river buffer, and proposed stormwater treatment measures described in the enclosed Engineering Report, will dramatically improve water quality on the Property.

> b) *The applicant's purpose for, and any feasible and prudent alternatives to, the proposed regulated activity which alternatives would cause less or no environmental impact to wetlands and watercourses. This consideration should include, but is not limited to, the alternative of requiring actions of a different nature which would provide similar benefits with different environmental impacts, such as using a different location for the activity.*

Pursuant to the Connecticut General Statutes, a *"feasible"* and *"prudent"* alternative includes one able to be *"constructed or implemented consistent with sound engineering principles"* which is *"economically and otherwise reasonable in light of the social benefits to be derived from the proposed regulated activity provided cost may be considered in deciding what is prudent and further provided a mere showing of expense will not necessarily mean an alternative is imprudent."*[2]

After considering several different development proposals, the Applicant is confident that the current proposal is the most feasible and prudent alternative for the Property. As shown on the submitted alternatives, other development scenarios would have produced a shorter

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[2] Conn. Gen. Stat. Sec. 22a-38(17) – Conn. Gen. Stat. Sec. 22a-38(18).

building; however, in order to ensure the project remained economically viable, those proposals also would have located the building and associated parking areas closer to the Norwalk River. These scenarios would encroach further into the Regulated Area than the proposed activity and would prohibit the significant investment in site landscaping currently proposed. Specifically, the March 2020 proposal would result in a building approximately 38' away from the edge of the Norwalk River, and a parking area located approximately 24' away from the edge of the Norwalk River. Similarly, the January 2021 proposal would result in a building approximately 40' away from the river's edge, and a surface parking area approximately 7'6" away from the river's edge. The current proposal, which locates the building no closer than 88' to the Norwalk River is far superior in terms of environmental impact.

In addition to setting the building back, the current proposal also incorporates:

- Catch Basins and yard drains fitted with 24" sumps to collect sediment and prevent discharge of oil and other pollutants into the storm drainage system;
- Hydrodynamic Separators to prevent the transport of oils and sediment further downstream, including Contech CDS units sized in accordance with the 2004 CTDEEP Stormwater Quality Manual; and
- Concrete chambers surrounded by stone and filter fabric designed to attenuate peak flows, serve as a primary treatment practice and promote groundwater discharge.

At the same time, the proposal will result in several important social benefits for the Town of Wilton (the **"Town"**). As noted in the 2019 Plan of Conservation and Development (the **"POCD"**), the "relatively high price of housing coupled with an available housing stock of detached single-family homes has more recently contributed to lower in-migration of younger working-age people and has increased the out-migration of empty-nesters and retirees."[3] Trends of increasing housing costs and decreasing housing supply have only been exacerbated by the COVID-19 Pandemic. At the same time, "the community has increasingly expressed interest in increasing housing type variety and price points in design and location appropriate ways" to increase the Town's overall housing stock and to attract and meet "the needs of occupants at different life and employment stages."[4] Moreover, the proposal would include an affordability component with 10% of the units available at prices affordable to families earning less than 80% of Area Median Income. With limited sites that are appropriate for multifamily residential development, the redevelopment of the Property for this purpose is necessary to achieve the Town's housing and economic development goals. For these reasons, the proposal is responsive to these trends and the vision identified in the POCD.

[3] POCD, pg. 8.
[4] Id.

In addition to increasing housing type, the proposal will result in the conversion of a paved parking area to a private park available for outdoor, recreational use. The replacement of impervious surface with a landscaped area planted with native species will enhance the environmental characteristics of the Property.

c) *The relationship between the short-term and long-term impacts of the proposed regulated activity on wetlands or watercourses and the maintenance and enhancement of long-term productivity of such wetlands or watercourses.*

No impacts on the wetlands or watercourses are anticipated. However, to mitigate any potential short-term impacts associated with site disturbance and construction, sediment and erosion controls will be implemented such as: silt fencing to trap sediments within stormwater runoff; anti-tracking pads to remove sediments from vehicles entering the Property; and watering of the Property as needed to prevent dust.

BMPs proposed to avoid long-term impacts include: catch basins fitted with sumps to trap sediments from roadway stormwater runoff; swirl concentrators designed to maintain water quality by trapping sediments, litter, oils and grease; and underground infiltration galleries to store and treat runoff.

d) *Irreversible and irretrievable loss of wetland or watercourse resources which would be caused by the proposed regulated activity, including consideration of the extent to which the proposed regulated activity would foreclose a future ability to protect, enhance or restore such resources. This requires recognition that the inland wetlands and watercourses of the State of Connecticut are an indispensable, irreplaceable and fragile natural resource, and that these areas may be irreversibly destroyed by deposition, filling, and removal of material, by the diversion, obstruction or change of water flow including low flows, and by the erection of structures and other uses.*

No deposition, filling, removal of material, diversion, obstruction or change of water flow is proposed in connection with the proposed redevelopment. The proposal will not result in the irreversible or irretrievable loss of wetland or watercourse resources. Rather, the proposal will better protect, enhance and restore these resources as compared to the existing impervious parking lot located within the Regulated Area. For example, the proposal will increase the width of the riparian buffer along the Norwalk River from 0' - 35'+/- to 60' - 100'+/-. This buffer will include 49 shade and understory trees, over 375 shrubs and over 500 perennials known to benefit pollinators.

e) *The character and degree of injury to, or interference with, safety, health, or the reasonable use of property, including abutting or downstream* *property, which would be caused or threatened by the proposed regulated activity, or the creation of conditions which may do so. This includes recognition of potential damage from erosion, turbidity, or siltation, loss of fish and wildlife and their habitat, loss of unique habitat having demonstrable natural, scientific or educational value, loss or diminution of beneficial aquatic organisms and wetland plants, the dangers of flooding and pollution, and the destruction of the economic, aesthetic, recreational and other public and private uses and values of wetlands and watercourses to the community.*

The proposal will not injure or interfere with the safety, health or reasonable use of the Property or abutting/downstream properties. In fact, building multifamily housing on the Property will facilitate the preservation of open space in other areas of Town that are better suited for passive, green space than multifamily residential use. BMPs employed during and after construction will protect the wetlands and watercourses on and adjacent to the Property. Currently, the Property provides little to no wildlife habitat due to existing improvements adjoining the Norwalk River and lacks water quality improvements. Modem stormwater systems and the planting of native species will protect against erosion, turbidity, and adverse impacts to wildlife and their habitat. Furthermore, replacing a parking lot with significant landscaping will increase the aesthetic and recreational value of the Property.

f) The environmental impact of the proposed regulated activity on the inland wetland or watercourse including the effects on the inland wetland's and watercourse's capacity to support desirable biological life, to prevent flooding, to supply and protect surface and ground waters, to control sediment, to facilitate drainage, to control pollution, to support recreational activities, and to promote public health and safety. Measures which would mitigate the impact of any aspect of the proposed regulated activity. Mitigation measures which may be considered as a condition of issuing a permit for such activity include but are not limited to, measures to (a) prevent or minimize pollution or other environmental damage, (b) maintain or enhance existing environmental quality, or (c) in the following order of priority: 1. restore, 2. enhance, and 3. create productive wetland or watercourse resources. Appropriate mitigation measures are those which could be feasibly carried out by the applicant and would protect the wetland's or watercourse's natural capacity to support fish and wildlife, to prevent flooding, to supply and protect surface and ground waters, including public water supplies to control sedimentation, to prevent erosion, to assimilate wastes, to facilitate drainage, to control pollution, to support recreational activities and open space, and to promote public health and safety.

Replacement of a surface parking lot with enhanced landscaping and updated water quality improvements will enhance the wetland and watercourse's ability to support desirable biological life, prevent flooding, supply and protect surface water and ground waters, control sediment, facilitate drainage, support recreational activities and promote public health and safety. These features will restore and enhance the productive wetland and watercourse resources on and near the Property.

IV. Feasible & Prudent Alternative Analysis

As stated in the Applicant's response to Section 10.3(b) above, the current proposal is the feasible and prudent alternative for the site. Other proposals would have located a building and/or parking areas closer to the Norwalk River with greater impact on the Regulated Area. This proposal appropriately sets the building and impervious improvements back from the Regulated Area, provides a robust landscaped recreational area and restores and enhances the natural environment. At the same time, the proposal will facilitate the Town's ability to respond to trends impacting housing cost and supply.

Environmental Land Solutions, LLC

Landscape Architecture & Environmental Planning
8 Knight Street, Suite 203, Norwalk, CT 06851
Tel: (203) 855-7879 Fax: (203) 855-7836

September 21, 2021

Inland Wetlands Commission
Town Hall Annex
238 Danbury Road
Wilton, CT 06897

Re: Response to a Memorandum from the Dr. Theodora Pinou, dated September 17, 2021
FDSPIN 141 DR, LLC,141 Danbury Road, Wilton, CT

Dear Members of the Commission:

ELS is in receipt of the memo provided by Dr. Theodora Pinou, dated September 17, 2021 and offers the following response for your consideration.

As noted in the submitted Environmental Land Solutions (ELS) report dated July 15, 2021, the existing riparian buffer on the property consists almost exclusively of asphalt, and there is no treatment of stormwater runoff from impervious surfaces which sheet flows directly into the Norwalk River. The project will result in the replanting of 25,020± sf of the river's shoreline (or 75% of the 100' wide upland review area). Pervious surfaces also extend well beyond the 100' upland review area which will aid to infiltrate stormwater runoff into the ground for renovation through bacterial action. These proposed activities along the 360' stretch of the Norwalk River are, in fact, a benefit and substantial improvement to the river's water quality, fisheries and terrestrial wildlife that also uses the river's edge. Indisputably, the proposed replacement of asphalt pavement and invasive nonnative shrubs with 49 trees, 375 shrubs and over 500 perennials will expand and enhance the wildlife habitat and wetland functions at this site. Notably, both the stormwater management design and proposed planting plan were recognized as a model for future development in the Conservation Commission's referral comments dated July 8, 2021 and attached here.

This work will be a benefit to the Norwalk River and its wetlands resource functions and values while expanding habitat for wetland wildlife species, by replacing the existing asphalt parking lot with restored buffer and recreation areas. A summary of functions and values used to provide functional analysis was taken from the publication entitled "<u>The Highway Methodology Workbook</u> *Supplement*, Wetland Functions and Values, *A Descriptive Approach*", prepared by the US Army Corps of Engineers (ACOE), NEDEP-360-1-30a, September 1999.

Based on the site plans set prepared by Tighe & Bond, and Environmental Land Solutions, LLC, last revised August 26, 2021, prepared for 141 Danbury Road, the chart below provides a summary of the anticipated development related impacts/benefits to the onsite wetland's functions.

WETLAND FUNCTION CHART: EXISTING vs. PROPOSED CONDITIONS

Wetland Function	Impact	Discussion
1. Groundwater Recharge / Discharge		
a. Groundwater Recharge:	Enhanced	Increases of pervious surfaces within and outside the 100' buffer pervious will expand the ability for groundwater recharge.
b. Groundwater Discharge:	Unchanged	The discharge rate of groundwater is anticipated to remain unchanged.
2. Floodflow Alteration:	Unchanged	The slight reconfiguration of the site will not significantly change the storage of flood waters.
3. Fish and Shellfish Habitat:	Enhanced	The improved buffer plantings and stormwater treatment will indirectly improve water quality of stormwater leaving the site and thereby improve fish habitat.
4. Sedimentation Retention:	Enhanced	The proposed 25,020 sf of planted wetland mitigation areas, that are currently paved asphalt, will improve the wetland's ability to trap sediments.
5. Nutrient Removal:	Enhanced	The proposed 25,020 sf buffer planting areas, that create mixed vegetation buffer from an existing paved parking lot, will increase the wetland's ability to remove excess nutrients from stormwater runoff by nutrient uptake. The proposed stormwater treatment will significantly improve stormwater quality that leaves this site.
6. Production Export:	Enhanced	The proposed 25,020 sf of planted buffer, that is currently a paved parking lot, will create additional food sources for wildlife.

7.	Sediment / Shoreline Stabilization:	Enhanced	The buffer planting will be expanded through replanting of the buffer.
8.	Wildlife Habitat:	Enhanced	The proposed 25,020 sf buffer planting, that is currently a paved asphalt parking lot, will improve the site's wildlife habitat by providing cover, food sources, nesting sites and roosting areas.
9.	Recreation	Enhanced	The proposed 25,0200 sf wetland buffer enhancements, that includes a walking path and lookout platforms, will expand the ability for viewing wetlands and photographing nature. This integration is consistent with the Norwalk River Valley Trail, Town of Wilton policies that bring people to this resource in the town parks and within Wilton Center. Access to regulated areas by humans is defined as a benefit to wetlands as per the referenced publication as well as Connecticut General Statutes Section 22a-36.
10.	Education / Scientific Value:	Enhanced	Access to the river will provide new opportunities to observe and appreciate wetland resources.
11.	Uniqueness / Heritage:	N/A	The onsite wetland is not unique.
12.	Visually / Aesthetics:	Enhanced	By integrating recreation into the buffer area, restoration will expand opportunities to observe and appreciate wetland resources, while providing opportunities to remove manmade debris and keep the shoreline free from litter.
13.	Habitat for Uncommon Species:	N/A	The wetland currently does not provide habitat for threatened, rare, or species of special concern.

In conclusion, while no work is proposed within the Norwalk River itself, the summary table clearly demonstrates that the proposed work within the 100' buffer, when completed, will have a beneficial impact to its associated function and values. The site plan purposefully integrates the new expanded river buffer with recreational areas, as these are recognized functions of wetlands and watercourse, as recognized by the ACOE.

While this proposal may not achieve complete restoration of the entire 100' buffer, it is clear that the proposed site work will not have an adverse effect on the river or wetland resources. On the contrary, when the site development is finished, it will create a beneficial impact to the rivers water quality, wildlife habitat and fishery as well as to the people who live in the new community.

Sincerely,

Kate Throckmorton, ASLA
Landscape Architect
Professional in Erosion and Sediment Control
Certified NOFA Professional

Matthew J. Popp, ASLA
Professional Wetland Scientist
Landscape Architect

MATTHEW J. POPP

Landscape Architect / Senior Professional Wetland Scientist

PROFESSIONAL HISTORY:

1995 - Present	Principal / Landscape Architect / Senior Professional Wetland Scientist Environmental Land Solutions, LLC, Norwalk, Connecticut
1987-1995	Landscape Architect / Environmental Analyst Environmental Design Associates, PC, Wilton, Connecticut

EDUCATION:

1983	The University of Connecticut, Storrs Bachelor of Science in Horticulture
1987	The University of Georgia, Athens Master's of Landscape Architecture

LICENSES AND CERTIFICATIONS:

State of Connecticut:	Landscape Architect #630
State of Connecticut (DEEP):	Permit to Collect Wildlife for Scientific / Educational Purposes (0323001)
State of Massachusetts	Landscape Architect #4065
State of New Jersey:	Landscape Architect #21AS0013400
State of New York:	Landscape Architect #1509-1
Society of Wetland Scientists:	Senior Professional Wetland Scientist #1322

AWARDS:

"2009 Honor Award" - Site Design of Cove Island Wildlife Sanctuary, Stamford, Connecticut.
Outstanding Professional Achievement from the American Society of Landscape Architects, CT Chapter.

PUBLICATIONS AND PRESENTATIONS:

"Can Tidal Wetlands Really Be Restored? A Case Study of the Science and Law of Tidal Wetland Restoration." Co-author. Wetlands Watch. Vol. 1, No.2. Robinson & Cole, Hartford, CT. Spring, 1991.

"Wetland Creation: Problems and Solutions." Co-author and Presenter at Society of Wetland Scientists 12th Annual Meeting, Ann Arbor, Michigan. 1990.

PROFESSIONAL AFFILIATIONS:

Member (1986 to present):	American Society of Landscape Architects
Board Member (1999 to 2008):	Audubon Greenwich, CT - President (2002 to 2005), Secretary (2001)
Board Member (2003 to 2013):	Calf Island Conservancy, Inc., Greenwich, CT - Treasurer (2012-2013)
Member (1988 to present):	Connecticut Botanical Society
Member (1991 to present):	Connecticut Ornithological Association
Board Member (2016 to present):	Friends of Greenwich Point, Greenwich, CT - Conservation Chair
Board Member (1995 to 1999):	Greenwich Audubon Society, CT - Vice President (1998-1999)
Member (1993 to 2009):	Inland Wetlands and Watercourses Agency, Town of Greenwich, CT
Member (2004 to present):	New England Hawk Watch
Volunteer (1995 to present):	Quaker Ridge Hawk Watch, Greenwich, CT - Director (1995-2002)
Member (2002 to present):	Society of Wetland Scientists - Senior Professional Wetland Scientist

EXPERIENCE:

The integration of landscape, ecology, design and culture to create sustainable site plans for a range of projects including parks, educational and health care institutions, mixed use and commercial developments, housing communities, single-family residences, and wetland restoration and mitigation. Natural resource inventories for both plant and wildlife communities. The preparation of environmental assessment reports with the evaluation of environmental impacts, mitigation, and alternatives for projects subject to local, state and federal review. Presentation of testimony at public hearings and meetings in support of our project. Site monitoring for permit compliance with regulatory permit conditions including erosion control and wildlife monitoring.

KATHERINE THROCKMORTON
Landscape Architect

PROFESSIONAL HISTORY:

1999 to Present	Principal / Landscape Architect / Environmental Analyst Environmental Land Solutions, LLC, Norwalk, CT
1992 to 1999	Assistant Planner Town of Wilton, CT
1987 to 1992	Landscape Architect Environmental Design Associates, P.C., Wilton CT
1984 to 1987	Landscape Designer Richard Bennett and Associates-Civil Engineers, Westport, CT
1983 to 1984	Landscape Designer Wesley E. Lent, Landscape Architect, Ridgefield, CT

EDUCATION:

1983	The University of Connecticut, Storrs Bachelors of Science in Landscape Design

PROFESSIONAL AFFILIATION:

Member (1986 to present):	American Society of Landscape Architects
Member (2007 to 2018):	Wilton Tree Committee - Chairman (2012 to 2018),
Member (1999-2010):	Conservation Commission, Town of Wilton, CT
Member (1992-1999):	Connecticut Trust for Historic Preservation
Member (1992-1999):	American Planners Association
Completed:	Northeast Organic Farming Association's (NOFA) Organic Land Care
Volunteer (2018 to present):	Wilton Land Conservation Trust, Trail Development
Broad Member (2020 to present)	Friends of Norwalk River Valley Trail (NRVT)

REGISTRATION:

Landscape Architect, Connecticut (#635)
Certified Professional in Soil Erosion and Sediment Control (#1216)
NOFA Accredited Organic Land Care Professional

EXPERIENCE:

Preparation of preliminary site drawings through construction documents for a range of project types including parks, athletic fields, commercial developments, single family residential and wetlands restoration and mitigation.

Site evaluations and inventorying of inland wetlands and wildlife communities. Preparation of environmental assessments reports with mitigation recommendations and alternative analysis for projects subject to local, state and federal review. Environmental monitoring of projects as required for regulatory compliance. Presentations at public hearing, meetings and court testimony. Site monitoring for permit compliance with regulatory permit conditions including erosion control and wildlife monitoring.

17 September 2021

Nick Lee, Chair and Members of the Wilton Inland Wetlands Commission
Town of Wilton/ Town Hall
238 Danbury Road
Wilton, CT 06897

RE: 141 Danbury Road, Wilton CT

The 141 Danbury Road application consists of approximately 4.28 acres adjacent to the Norwalk River. The applicant seeks to convert the warehouse style office building and large surface parking lot (extending to the river's edge) into a 173 unit (317 bedroom) apartment complex. The application claims to restore and expand functions to the current insignificant habitat and non-existent riparian buffer. To this end, the applicant proposes "*significant*" planting of the 100-foot upland review area that includes a 300± foot, point to point, river's edge perimeter, or estimated 360 feet if you consider the natural characteristics of the meandering edge of the Norwalk River. The applicant admits that the impervious surface will increase overall, but claims that the "*significant improvements to the river buffer and new stormwater drainage system will dramatically improve water quality leaving the site,*" to empty directly into the Norwalk River. The applicant implies that their riparian buffer plan will also enhance the current non-existent wildlife habitat, by providing "*food, nesting, and cover for local and migrating wildlife.*" The application adds, that their riparian buffer restoration will "*provide outdoor, passive recreation space for residents.*"

The Norwalk River is a significant habitat. In 2019 the Wilton Bulletin reported on a CT Department of Energy and Environmental Protection (DEEP) fish count of the Norwalk River that revealed significant diversity and abundance of fish swimming and spawning in the Norwalk River. Such counts and water quality monitoring activities are invaluable for sustaining the fisheries, and recreational fishing, that the Norwalk River supports. Of special interest is the return of the American Eel, whose numbers are increasing since Norwalk River restoration projects began to restore natural flow and increase habitat complexity. This same article cautioned about persistent challenges to the Norwalk River including control of impervious surfaces stormwater runoff containing contaminants (i.e., chemical and microbiological), and increased water temperatures and reduced oxygen levels due to impoundments and restricted water flow. Significant, well designed, thoughtfully complex riparian vegetative buffers with healthy mycorrhizal soils can sequester nutrients, and absorb microorganisms known to impair water and compromise fisheries and wetland habitat (Chen et al., 2019). Additionally, predicted changes to climate in our area will result in more frequent storm surges (see attached EPA 430-F-16-009), and these surges can quickly overwhelm poorly designed stormwater management systems based on legal yet outdated design models that underestimate the frequency of future storm surges. The consequence of overwhelming dated pervious stormwater systems, is flashes of dirty surface water pouring directly into rivers with insignificant riparian buffers.

The buffer restoration proposed here will do little, in my opinion, to increase and sustain local wildlife such as birds and small mammals. A couple of rows of shrubs and trees along the river edge, coupled with lookout platforms, that are inviting to human traffic and pets, will not build a riparian buffer that will attract or sustain wildlife, or a wildlife corridor, but will provide opportunity for unintended personal debris, invasive microorganisms and biologicals, and secondary pollution (thermal, light, noise) proximity to the river's edge that otherwise would not be there. In my expert opinion, I find the proposed restoration of the riparian buffer too narrow and too manicured. Only 30 feet in the south west corner of the property where the buffer is approximately 80 feet wide may function as an effective riparian vegetative buffer. This represents approximately 8% of the estimated 360-foot-long Norwalk River edge owned by this applicant. Connecticut fisheries and EPA data driven research recommend 100ft riparian buffer widths with substantial mycorrhizal soils to support safe fisheries, restore healthy habitats, and control stormwater runoff and erosion. A wider, less managed, more complex riparian buffer throughout the length of the river's edge, as well as restricted access to the water's edge, will greatly improve the wildlife and habitat restoration objectives of this application, as well as increase the preventive maintenance and management of stormwater runoff into the river due to storm surges predicted in the next decade. This improved riparian buffer will also help prevent snow melt, rich in sand and salt, from unintentionally impairing the Norwalk River. Climate change models for Connecticut predict greater precipitation in the winter and spring, suggesting that greater than expected snowmelt should be anticipated. In anticipation of this snow melt, snow storage should be stored furthest from the river's edge and in deeper/more recessed basins than currently planned.

Respectfully submitted,

Theodora Pinou, Ph.D.

- **Inland Wetlands and Watercourses Act** (IWWA): Connecticut General Statues (CGS) Sections 22a-36 through 22a-45

CH 440: Wetlands and Watercourses: Sec. 22a-36. Inland wetlands and watercourses. Legislative finding. The inland wetlands and watercourses of the state of Connecticut are an indispensable and irreplaceable but fragile natural resource with which the citizens of the state have been endowed. The wetlands and watercourses are an interrelated web of nature essential to an adequate supply of surface and underground water; to hydrological stability and control of flooding and erosion; to the recharging and purification of groundwater; and to the existence of many forms of animal, aquatic and plant life. Many inland wetlands and watercourses have been destroyed or are in danger of destruction because of unregulated use by reason of the deposition, filling or removal of material, the diversion or obstruction of water flow, the erection of structures and other uses, all of which have despoiled, polluted and eliminated wetlands and watercourses. Such unregulated activity has had, and will continue to have, a significant, adverse impact on the environment and ecology of the state of Connecticut and has and will continue to imperil the quality of the environment thus adversely affecting the ecological, scenic, historic and recreational values and benefits of the state for its citizens now and forever more. The preservation and protection of the wetlands and watercourses from random, unnecessary, undesirable and unregulated uses, disturbance or destruction is in the public interest and is essential to the health, welfare and safety of the citizens of the state. It is, therefore, the purpose of sections 22a-36 to 22a-45, inclusive, to protect the citizens of the state by making provisions for the protection, preservation, maintenance and use of the inland wetlands and watercourses by minimizing their disturbance and pollution; maintaining and improving water quality in accordance with the highest standards set by federal, state or local authority; preventing damage from erosion, turbidity or siltation; preventing loss of fish and other beneficial aquatic organisms, wildlife and vegetation and the destruction of the natural habitats thereof; deterring and inhibiting the danger of flood and pollution; protecting the quality of wetlands and watercourses for their conservation, economic, aesthetic, recreational and other public and private uses and values; and protecting the state's potable fresh water supplies from the dangers of drought, overdraft, pollution, misuse and mismanagement by providing an orderly process to balance the need for the economic growth of the state and the use of its land with the need to protect its environment and ecology in order to forever guarantee to the people of the state, the safety of such natural resources for their benefit and enjoyment and for the benefit and enjoyment of generations yet unborn.

frontiers in Plant Science

REVIEW
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Beneficial Services of Arbuscular Mycorrhizal Fungi – From Ecology to Application

Min Chen[1], *Miguel Arato*[2], *Lorenzo Borghi*[3], *Eva Nouri*[1] *and Didier Reinhardt*[1]*

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Arbuscular mycorrhiza (AM) is the most common symbiotic association of plants with microbes. AM fungi occur in the majority of natural habitats and they provide a range of important ecological services, in particular by improving plant nutrition, stress resistance and tolerance, soil structure and fertility. AM fungi also interact with most crop plants including cereals, vegetables, and fruit trees, therefore, they receive increasing attention for their potential use in sustainable agriculture. Basic research of the past decade has revealed the existence of a dedicated recognition and signaling pathway that is required for AM. Furthermore, recent evidence provided new insight into the exchange of nutritional benefits between the symbiotic partners. The great potential for application of AM has given rise to a thriving industry for AM-related products for agriculture, horticulture, and landscaping. Here, we discuss new developments in these fields, and we highlight future potential and limits toward the use of AM fungi for plant production.

Keywords: arbuscular mycorrhiza, symbiosis, abiotic stress, plant growth, plant protection, plant nutrition, soil structure, Glomeromycota

OPEN ACCESS

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INTRODUCTION

If an innovation spreads globally, becomes adapted to a multitude of diverse applications and persists over eons of time, it can be considered a great success. This is certainly the case for arbuscular mycorrhiza (AM). AM is thought to have a monophyletic origin in the Ordovician, approximately 480 Mio years ago (Redecker et al., 2000; Delaux, 2017), and it is found in the majority of land plants in most taxa and virtually all ecological niches (Read, 2002; Wang and Qiu, 2006). Most land plants are facultative symbionts, i.e., they profit from AM fungi, but can also live without them, although at considerable fitness costs (see below). However, some plant species have turned to obligate parasites on the AM fungus, i.e., they became fully dependent on fungal nutrition and lost photosynthetic capacity (mycoheterotrophs) (Graham et al., 2017). On the other end of the scale, some plant taxa, e.g., the *Brassicacea* and *Chenopodiaceae*, became asymbiotic, i.e., they lost the capacity to interact with AM fungi and evolved alternative strategies to meet their nutritional needs (Brundrett, 2004).

Arbuscular mycorrhiza symbiosis is thought to be a largely promiscuous association between > 100,000 plant species and a few 100 AM fungal morphotypes, which have long been regarded as the equivalent of species. However, due to the relatively few distinctive morphological features of AM fungi (primarily associated with spores), and due to their essentially asexual mode of propagation, the traditional species concept is problematic in the context of AM fungi. AM fungi have never been shown to form sexual stages or to mate, however, they can undergo hyphal fusion (anastomoses) and exchange genetic material, thereby reshuffling their genomes and generating new genetic diversity in the absence of classical meiosis and recombination (Chagnon, 2014). Anastomosis depends on genetic relatedness, hence this feature could potentially be used as an additional criterion to define taxonomic units besides spore morphotypes.

With the advent of large scale sequencing approaches, AM fungal taxonomy and systematics rose to a new level (Spatafora et al., 2016). Results obtained with these modern tools indicate that the diversity of AM fungi has been underestimated (Husband et al., 2002; Öpik et al., 2006, 2013; Lee et al., 2013). Hence, the true number of AM fungal species, including genetically and functionally distinct "cryptic species" that cannot be distinguished by morphometric parameters (Munkvold et al., 2004; Rosendahl, 2008; Chen et al., 2018; Savary et al., 2018), may exceed current estimates by orders of magnitudes. The fact that recent results have documented unprecedented genetic variability even within one AM fungal species at a given site (Chen et al., 2018) points to the fact that the peculiar genetics and mode of reproduction of AM fungi impede with systematics and nomenclature in AM fungi.

ORIGIN AND EVOLUTION OF AM

Recent evidence indicates that the evolution of early plants from non-photosynthetic eukaryotes occurred in a freshwater environment by engulfment and domestication of a photosynthetic cyanobacterium (which subsequently evolved to the chloroplasts) (Ponce-Toledo et al., 2017). Hence, plants are the result of an endosymbiosis that was successful enough to allow them to radiate through most aquatic environments. Which innovations allowed plants to subsequently conquer the dry land masses of the continents? Some of the obvious adaptations required for the colonization of this new environment include protection against high radiation, a water-impermeant cuticle, and water-conductive vascular systems. However, an equally important innovation was required to allow plants to acquire water and nutrients from the substrate in the absence of specialized absorptive organs such as roots, which only evolved later (Brundrett, 2002). Conceivably, fungal symbioses were instrumental to allow the colonization of land by descendants of freshwater algae (Bidartondo et al., 2011; Delwiche and Cooper, 2015; de Vries and Archibald, 2018).

Although associations with AM fungi may not have been the first fungal symbiosis of early land plants (Field et al., 2015), recent evidence suggests that the advent of AM in the early land plants was a unique event, hence, AM appear to be a monophyletic innovation that may have enabled the rapid colonization of the continents by vascular plants (Delaux, 2017). Thus, it is conceivable that early rootless plants engaged in various kinds of fungal associations, as they are still observed today in early-diverging plant lineages (Read et al., 2000), and that roots coevolved with AM in the vascular plants (Brundrett, 2002). AM fungal associations were so successful that still the majority of land plants in most ecological niches (except for aquatic environments) engage in this symbiotic association.

MECHANISMS INVOLVED IN INTRACELLULAR ACCOMMODATION OF AM FUNGI

The very long evolutionary history of AM symbiosis of more than 400 Mio years (Redecker et al., 2000; Heckman et al., 2001; Schüssler et al., 2001), and the involvement of plant-derived and fungal signaling molecules that promote AM (Gutjahr and Parniske, 2013), suggests a high degree of adaptation and genetic/metabolic coordination between mycorrhizal partners. Indeed, formation of AM requires a dedicated signaling pathway starting with the root-borne signal strigolactone, which is exuded to stimulate AM fungal activity (Akiyama et al., 2005; Besserer et al., 2006; Kretzschmar et al., 2012). AM fungi subsequently secrete lipochito-oligosaccharides, which are perceived by the plant and activate a signal transduction pathway that is shared with root nodule symbiosis and therefore is known as the common symbiosis signaling pathway (CSSP), which has been elucidated in great detail in recent years (Harrison, 2012; Gutjahr and Parniske, 2013). In the light of the very low host specificity in AM, the involvement of a bidirectional exchange of symbiosis signals challenges our current understanding of communication between the partners, since it would require either many alternative signals for each potential partner, or few signals that can be recognized by a wide range of potential partners.

While central questions related to recognition and infection remain open, a rich body of microscopic evidence shows that at later stages the interaction has a very high degree of coordination at the cellular level. The most impressive examples are the formation of an infection structure (prepenetration apparatus; PPA) that allows cellular invasion (Genre et al., 2005, 2008), and the formation of the intracellular arbuscules that serve as nutritional interface between the partners (Harrison, 2012; Gutjahr and Parniske, 2013). Although the molecular-genetic basis of PPA formation is elusive, PPAs are thought to be a prerequisite for AM fungal infection of host roots, and to require signaling through the CSSP (Genre et al., 2005). Establishment of AM is associated with a fundamental reprogramming of the host cells including the activation of hundreds of genes (Liu et al., 2003; Güimil et al., 2005; Hohnjec et al., 2005; Fiorilli et al., 2009; Gomez et al., 2009; Guether et al., 2009; Breuillin et al., 2010; Gaude et al., 2012; Tromas et al., 2012; Hogekamp and Küster, 2013; Calabrese et al., 2017), of which some are expressed primarily or exclusively in cells with arbuscules. Although these genes are thought to be required for intracellular accommodation of the fungus, and for coordination of symbiotic functions, their molecular and cellular function has been elucidated only in few cases (see below).

NEW PARADIGMS IN THE EXCHANGE OF BENEFITS IN AM SYMBIOSIS

The finely branched fungal arbuscules (**Figure 1A**), and the surrounding peri-arbuscular membrane of the host (**Figure 1B**),

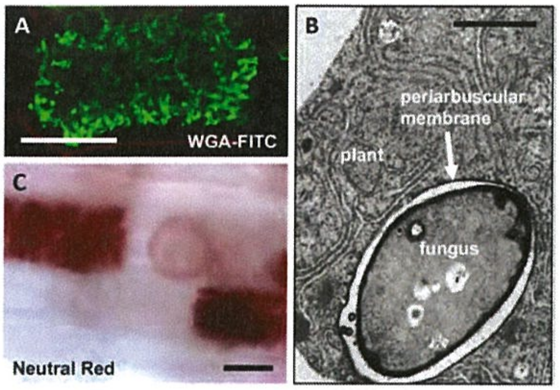

FIGURE 1 | Characteristics of AM fungal arbuscules. **(A)** Arbuscules are highly branched hyphal structures that nearly fill the cortex cells of the host. Green staining of fungal structures with wheat germ agglutinin (WGA) coupled to fluorescein isothiocyanate (FITC), red staining of the cell wall with propidium iodide (from Kretzschmar et al., 2012). **(B)** Transmission electron micrograph of a colonized host cell with an arbuscular branch (fungus), surrounded by the periarbuscular membrane. **(C)** A colonized root stained with Neutral Red which accumulates in acidic compartments, in this case the space between the periarbuscular membrane and the fungal cell wall [compare with **(B)**]. Size bars, 20 μm in **(A,C)**; 1 μm in **(B)**.

represent a considerably increased contact surface (also known as symbiotic interface) between the two partners, which has been estimated to correspond to a multiple of the entire cell surface (Alexander et al., 1989). In addition, the symbiotic interface is acidified (**Figure 1C**) to energize nutrient transport across the fungal plasma membrane and the periarbuscular membrane (Guttenberger, 2000; Krajinski et al., 2014; Wang et al., 2014). Therefore, cells with arbuscules are ideally suited for nutrient exchange. Indeed, the plant host expresses many symbiosis-specific nutrient transporters that are thought to mediate mineral nutrient uptake from the AM fungus (Rausch et al., 2001). The best-characterized example is a symbiotic phosphate transporter (PT) that is expressed exclusively in cells with arbuscules (MtPT4 in *Medicago truncatula*; OsPT11 in rice) (Harrison et al., 2002; Yang et al., 2012). Phylogenomic analysis of MtPT4 and its orthologs in other land plants suggests that the AM-related phosphate uptake pathway represents an early evolutionary innovation that became conserved after the advent of the angiosperms (Vigneron et al., 2018). Phosphate delivery is among the most important benefits for the host in AM symbiosis (Karandashov and Bucher, 2005), and the collective information suggests that the arbuscules are the site of transfer of phosphate from the fungus to the plant (MacLean et al., 2017).

The induction of many other mineral nutrient transporters in mycorrhizal roots (Wang et al., 2017), and the fact that mycorrhizal plants contain increased amounts of various mineral nutrient elements (Clark and Zeto, 2000; George, 2000) suggest that nutrient elements such as nitrogen, sulfur, and microminerals such as copper and zinc may also be transferred via the arbuscules. However, for most AM-induced predicted nutrient transporters, the expression pattern, protein localization, and function remain to be established.

Interestingly, AM-related pathways can also stimulate plant growth and physiology in nutrient-independent ways. For example, mycorrhizal plants show enhanced photosynthetic capacity (Boldt et al., 2011). More strikingly, the overexpression of a petunia strigolactone transporter (PDR1), which is involved in AM signaling (Kretzschmar et al., 2012), is sufficient to improve root and shoot growth in the absence of AM fungi (Liu et al., 2018). Thus, AM and its signaling can potentially increase plant growth in yet unexplored ways that are more related to plant developmental programs than to plant nutrition.

As a reward for its symbiotic services, the AM fungus receives fixed carbon from the plant. In analogy to plant pathogen interactions, carbon transfer has long been thought to proceed in the form of carbohydrates (in particular hexoses). Indeed, a large body of evidence has demonstrated that AM fungi can take up and utilize sugars, but only under symbiotic conditions in the roots (Roth and Paszkowski, 2017). Recently, the surprising discovery that two AM fungal genomes lack a fatty acid synthase complex (Wewer et al., 2014; Tang et al., 2016) has raised the question how AM fungi may generate their abundant lipid reserves in spores and vesicles (Rich et al., 2017b). Intriguingly, the plant host induces several components of fatty acid biosynthesis and processing in mycorrhizal roots indicating that AM fungi may also receive fatty acids besides sugars. Indeed, recent evidence has demonstrated that AM fungal lipids are, at least partially, derived from the plant host (Bravo et al., 2017; Jiang et al., 2017; Keymer et al., 2017; Luginbuehl et al., 2017; Brands et al., 2018).

The supply of lipids to AM fungi involves host genes encoding enzymes of fatty acid biosynthesis, a glycerol-3-phosphate acyl transferase (GPAT) that generates a monoacylglycerol (MAG) intermediate and a pair of ATP-binding cassette transporters of the G-type (ABCGs) that form a heterodimeric transporter in the peri-arbuscular membrane (Zhang et al., 2010). These elements resemble components required for the generation and secretion of the lipid precursor for the extracellular lipid polyester cutin, suggesting that the two pathways may share a common evolutionary origin in early land plants (Rich et al., 2017b). The AM-specific transcription factor REQUIRED FOR ARBUSCULAR MYCORRHIZA1 (RAM1) in the host is responsible for induction of many of the genes required for a functional AM, including the GPAT RAM2 and the ABCGs STUNTED ARBUSCULE (STR) and STR2 (Park et al., 2015; Rich et al., 2015; Pimprikar et al., 2016; Luginbuehl et al., 2017; Rich et al., 2017a). However, many aspects of lipid transfer to AM fungi remain to be elucidated.

SIGNIFICANCE OF AM FOR PLANTS IN NATURAL HABITATS

How much a plant benefits from AM fungal colonization depends to a large degree on the environmental conditions. In most natural environments, which are characterized by mineral nutrient deficiency and various abiotic stress conditions, mycorrhizal plants are thought to have a selective advantage over non-mycorrhizal individuals of the same species. Thus, AM can potentially promote intraspecific competitiveness and selectively favor mycorrhizal plants. Conceivably, this is the reason why AM symbiosis has prevailed over very long periods of evolutionary time in most land plant taxa.

A complication arises due to the fact that plants can have several different AM fungal partners, and *vice versa*, each fungal mycelium can infect several host plants of the same or different species. The resulting common mycorrhizal networks (CMNs) add an additional level of complexity to the analysis of benefits in mycorrhizal interactions (Jakobsen and Hammer, 2015). A strongly interconnected plant community can potentially gain stability because weaker individuals could profit from mineral nutrient supply from the CMN at the expense of stronger plants that entertain the CMN. In this way, the stronger plants indirectly benefit less competitive plants, thereby attenuating competition among plant individuals. Such "underground socialism" has been envoked particularly in cases where seedlings grew better when they were connected to a CMN that had been established by older plants, a phenomenon known as facilitation (van der Heijden and Horton, 2009). However, the effects of CMN on seedlings are highly context-dependent and vary with the involved species. In some cases, AMF can even increase intra- or interspecific competition, hence, the effects of CMN cannot be generalized. In the most extreme version of the theme, achlorophyllous plants obtain all their resources, including carbon, from CMN, thereby parasitizing—indirectly—on other plants that supply the network with their carbon (Bidartondo et al., 2002). While this represents an extreme nutritional strategy that emerged only in a minority of land plants, there are many intermediate examples of plants that obtain part of their carbon from mycorrhizal fungi (mixotrophy), a condition that has likely been the transitional evolutionary phase from autotrophy to mycoheterotrophy (Bidartondo, 2005; Selosse et al., 2017).

FUNCTIONAL SPECIFICITY IN AM INTERACTIONS

The variability of the effects of AM fungi on their hosts (see above) indicates that certain combinations are beneficial for the plant, whereas others are neutral or even negative. Conversely, AM fungal proliferation and sporulation are highly dependent on plant host identity (Bever, 2002). These findings suggest a certain degree of functional specialization in AM interactions. Indeed, a systematic combinatorial study on mycorrhizal benefits employing a large panel of plant and fungal species from different geographical locations showed that the mycorrhizal growth response (MGR; defined as the difference between the weights of mycorrhizal vs. non-mycorrhizal plants) ranged from −50% to +50% growth promotion, with almost half of the combinations resulting in growth depression (**Figure 2**) (Klironomos, 2003). The mutualistic potential did not correlate with phylogenetic patterns in either partner, indicative of adaptive mechanisms independent from lineage. Interestingly, combinations of partners isolated from the same location performed better, indicative of co-adaptation. Conceivably, combinations of good mutualists enjoy positive bidirectional feedback that results in progressive mutual adaptation of the most effective mutualistic combinations (Kiers and Denison, 2008), although the interaction shows very little host specificity at the level of infection (see above). In agreement with functional specialization, soils with a diverse AM fungal flora can support more diverse plant communities than if only one or few AM fungi are present (van der Heijden et al., 1998). This finding is compatible with a scenario in which each plant species requires a suitable AM fungal partner. Thus, despite the very low host specificity of AM under laboratory conditions, functional specialization within the AM fungal community shapes the level of the biodiversity and productivity of plant communities.

EFFECTS OF AM FUNGI ON PLANT DEFENSE AND DISEASE RESISTANCE

Mycorrhizal roots often exhibit very intense fungal colonization, both intercellularly and intracellularly, that can reach more than 90% total root length. This observation has led Dangeard to coin the genus name *Rhizophagus* (greek for "root eater"), based on the initial assumption that mycorrhizal roots were colonized by an aggressive pathogen (Dangeard, 1900). We now know that most plants can potentially profit from AM fungal colonization (depending on the right fungal partner and the environmental conditions), but it is still a mystery how plants can tolerate such high degrees of colonization without mounting a defense response, given that fungi in general (including AM fungi) contain and release many molecular signals (e.g., chitin oligomers) that can be recognized by plants, and that have shown to trigger defense responses in various plant species (Wan et al., 2008; Boller and Felix, 2009). It has therefore been proposed that AM involves the suppression of defense. Indeed, plant mutants defective in genes required for symbiotic signaling and AM establishment (see above) often show characteristic defense responses upon infection by AM fungi, indicating that these fungi have potent signaling molecules that trigger defense, and that these mechanisms are suppressed during normal AM development. Pathogens usually produce inhibitors of defense (known as effectors), and recently, numerous effectors where also predicted to occur in the genomes of AM fungi (Sedzielewska Toro and Brachmann, 2016; Kamel et al., 2017). However, only very few of them have been functionally analyzed (Kloppholz et al., 2011).

Although defense mechanisms in the host have to be attenuated to allow AM fungal infection and colonization of the roots, general defense needs to remain active to cope with rhizospheric pathogens. Indeed, general disease resistance of mycorrhizal plants is not decreased. In contrast, mycorrhizal plants often exhibit increased disease resistance (Borowicz, 2001; Pozo and Azcon-Aguilar, 2007; Jung et al., 2012; Cameron D.D. et al., 2013). Experiments with split root systems revealed that this effect is often systemic, i.e., the entire plant is protected against pathogens. This can involve generally improved plant health due to better nutrition, or a systemic induction of the defense status, known as systemic acquired resistance (SAR). In addition, mycorrhizal plants may be prepared to react faster and

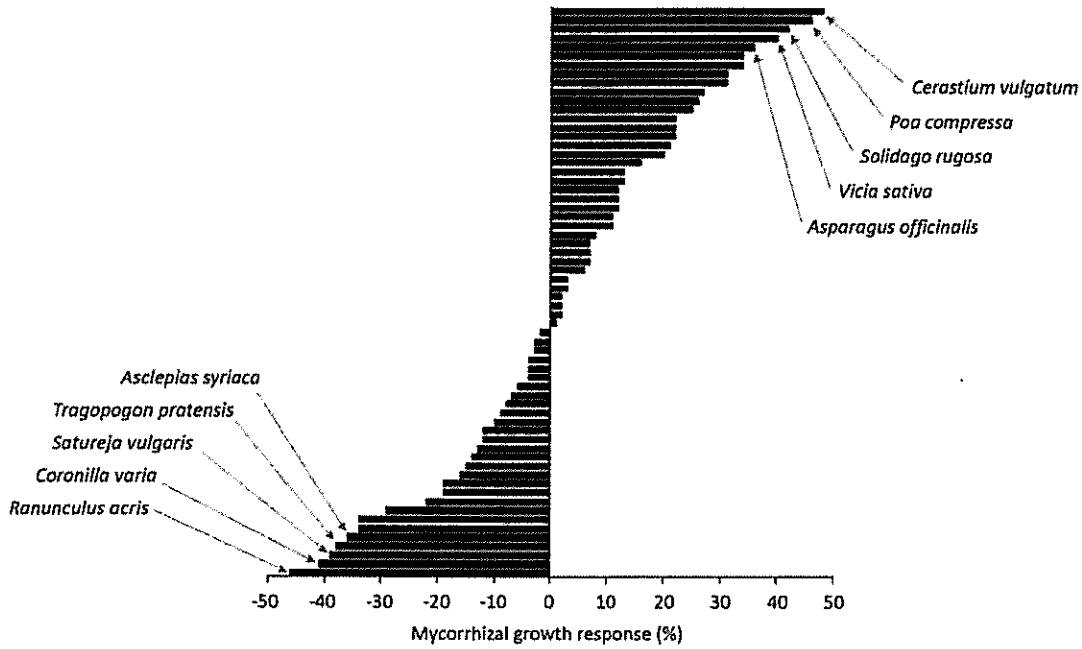

FIGURE 2 | Mycorrhizal growth response (MGR) depends on the symbiotic partners. Various plants were inoculated with *G. etunicatum*. After 16 weeks of coculture, the dry weight of the host plants was determined and the percent change relative to the non-mycorrhizal controls (referred to as MGR) was calculated. MGR ranged between −50% and +50% change in dry weight. The 10 most responsive plants (five positive, five negative) are indicated (modified from Klironomos, 2003).

stronger to pathogen attack, a phenomenon known as induced systemic resistance (ISR), or priming (Conrath et al., 2006). These protective effects of AM are of great interest for sustainable strategies of plant protection (Solaiman et al., 2014). Although priming is a systemic phenomenon, AM fungi are primarily employed to protect plants from soil-borne pathogens (Cameron D.D. et al., 2013; Jung et al., 2012). In addition, AM fungi, or other microbes associated with their mycelium, can directly interfere with rhizospheric pathogens either by the release of antimicrobial compounds, or by direct competition for space and resources. Although the potential of AM fungi for plant protection is widely acknowledged, it should be noted that in certain cases, mycorrhizal crops have no benefits from AM, or may even exhibit reduced growth and fitness (Jacott et al., 2017) (see also above). It is tempting to speculate that this phenomenon may be related to breeding programs that targeted traits related to shoot architecture and yield, while root-related traits were ignored. While this does not necessarily prevent plants from becoming infected, it may have interfered with the regulatory mechanisms that ensure optimal metabolic coordination of both partners.

SIGNIFICANCE OF AM IN THE MAJOR CLIMATIC ZONES AND IN MANAGED ECOSYSTEMS

Arbuscular mycorrhiza fungi have been observed in virtually all major ecosystems worldwide (Öpik et al., 2006), from arctic regions (Varga et al., 2015), to tropical forests (Lovelock et al., 2003), from the deserts in the arabic peninsula (Al-Yahya'ei et al., 2011) to the high himalayans (Liu et al., 2011). While some AM fungal isolates show only restricted distribution in natural communities, others appear to be true cosmopolitans (Rosendahl et al., 2009). Whether this reflects natural distribution, or transport by human activity is unclear. In addition, some cosmopolitan species may in fact represent genetically differentiated species complexes that cannot be distinguished by morphological criteria. The occurrence of truly cosmopolitan AM fungal species (Rosendahl et al., 2009) suggests that these fungi are extremely adaptable, both, in terms of environmental conditions, and in terms of a wide host range. Since AM fungi play an instrumental role in the protection against abiotic stresses such as nutrient starvation (see above), heat (Bunn et al., 2009), and drought (Augé, 2001; Ruiz-Sanchez et al., 2011; Rapparini and Penuelas, 2014; Chitarra et al., 2016), they can benefit their hosts in the wild and in agriculture (Wu, 2017). Consequently, AM fungi are thought to have a great impact in natural environments (Read, 2002; Smith and Read, 2008; van der Heijden et al., 2015), as in managed conditions in agriculture, horticulture, and forestry (see below).

REDUCTION OF SOIL EROSION AND NUTRIENT LEACHING BY AM

An important service of AM fungi in natural as well as in agricultural contexts is the beneficial alteration of soil structure

(Leifheit et al., 2014). The dense hyphal network of the highly ramified AM fungal mycelium creates a three-dimensional matrix that enmeshes and crosslinks soil particles without compacting the soil. A soil glycoprotein was identified as an additional important agent in the stabilization of soil aggregates (Rillig, 2004; Singh et al., 2013). It is referred to as glomalin, because it is thought to be produced by AM fungi. Glomalin is not a defined gene product or chemically homogenous molecular species, rather, it is a soil fraction that is defined by its extractability and immuno-reactive properties (Rillig, 2004). Glomalin and glomalin-related soil proteins (GRSPs) have recently seen a renaissance in the literature, however, their origin and function are far from clear. Nevertheless, they represent an important determinant of soil quality and a very stable carbon sink with estimated half-life times in the range of several years up to decades (Rillig et al., 2001). GRSPs can account for a significant fraction of total organic soil carbon (2–5%), and since they protect other forms of organic carbon from degradation by increased soil particle aggregation, they may contribute significantly to sequestration of carbon in the soil (Rillig et al., 2001; Wilson et al., 2009). Taken together, the hyphal network of AM fungi, and their promoting effects on plant growth and root system development (Gutjahr and Paszkowski, 2013) protects the soil from erosion by wind and water.

The collective effects of AM fungi on soil qualities also results in higher water retention capacity, which benefits plant growth in addition to improved nutrient supply. The benefits of AM fungi are particularly critical for plants in dry sandy soils in arid regions. These soils often show low fertility and are highly vulnerable to erosion by wind and rain. In such cases, plantings with mycorrhizal plants can be a sustainable way to counteract erosion and improve soil fertility (see below).

Apart from the improved soil structure, AM fungi reduce nutrient leaching from the soil (Cavagnaro et al., 2015). Nutrient leaching is a serious problem since it results in loss of soil fertility and pollution of ground water and surface water (rivers, lakes). Intact ecosystems exhibit a good nutrient retention capacity due to efficient adsorption and retention of nutrients by roots and soil microorganisms (including AM fungi). However, agricultural soils are by definition disturbed by agricultural practice (in particular plowing), and they receive large amounts of fertilizer, mainly N, P, K. These, in particular the highly mobile nitrate, are prone to be washed out from the soil due to the lack of a good nutrient retention system (Cameron K.C. et al., 2013).

The beneficial effects of AM fungi against nutrient leaching operate at different levels. First, improved soil structure (see above) allows for increased nutrient sequestration to the micro- and macro-aggregates in mycorrhizal soil, second, AM fungi take up nutrients from the soil solution (Clark and Zeto, 2000; George, 2000), and final, mycorrhizal soils exhibit better retention capacity of the soil solution (see above) (Querejeta, 2017), thereby benefitting at the same time the availability of nutrients and water to the plant. A detailed documentation of the beneficial effect of AM fungi on plants under drought stress was reported for tomato (Bitterlich et al., 2018). Reduced leaching from mycorrhizal soils has been documented in particular for P and N, but it conceivably also involves other mineral nutrients. Taken together, AM fungi integrate the nutrient fluxes in the soil by generating closed nutrient cycles, thereby promoting long-term soil fertility (Cavagnaro et al., 2015).

COMMERCIAL USE OF AM FUNGI

The multiple benefits of AM have raised opportunities for their commercial application. Consequently, the AM-related markets grew considerably during the past decades, with increasing numbers of actors, products and market volume (Vosatka et al., 2008). However, due to the fact that most of the AM-related industry consists of privately owned relatively small firms, public information about the dynamics of market shares are scarce. Hence, we carried out a systematic survey on the number of firms producing and selling AMF products in Europe and worldwide, and we assessed the number of their products as key figures in the market.

The results show that since the 1990s, the number of companies selling mycorrhizal products has increased considerably. On a global scale, the main players are located in North America, Europe, Asia, and Latin America. In the domain of the Americas, the main markets include United States, Canada, Mexico, Brazil, Argentina, Colombia, and Chile. The Asia region is mainly dominated by India, followed by China. The Indian market itself has seen an outstanding growth rate during the last decade. One of the reasons is the promotion of mycorrhiza-based bio-stimulants by the Indian government and the actions from organizations such as The Energy and Resources Institute (TERI[1]). In general, the AMF businesses are small- and medium-sized firms producing for the local and regional markets. However, there are some exceptions of larger companies from the United States, Canada, Germany, Italy, Czech Republic, United Kingdom, and Spain that export their products to various geographical regions.

The European market represents one of the leading markets for mycorrhizal bio-stimulants. In Europe itself, the number of firms producing and selling AMF-products has increased from less than 10 firms in the late 1990s, to more than 75 firms in 2017 (**Figure 3**). Most of the European companies are found in Germany, Italy, Spain, the United Kingdom, France, The Netherlands, Czech Republic, Austria, Belgium, Estonia, and Switzerland (**Figure 4**). The largest domains of application include gardening and landscaping, horticulture, agriculture, forestry, golf courses (in particular greens), recultivation of degraded land, roof plantings, soil remediation, and research (**Figure 5**). In terms of retail prices for hobby and semi-professional users, the average price per plant ranges between 10 and 50 cents. The cost of mycorrhizal inoculation for professional uses at an agricultural scale is considerably lower, with an estimated investment of 135 $ per hectare in the case of potato in the United States (Hijri, 2016). Apart from pure AM fungal inocula, many products include mixed fungal inocula, sometimes in combination with ectomycorrhizal fungi or with plant growth promoting rhizobacteria.

[1] http://www.teriin.org

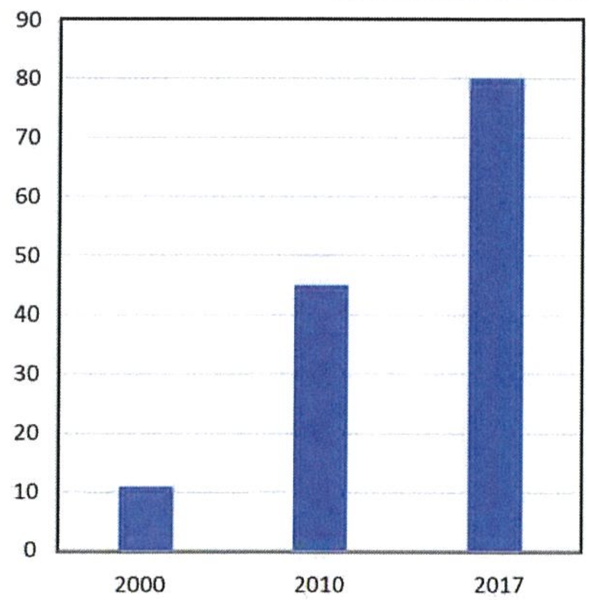

FIGURE 3 | Increase in the number of companies in the European AM market. A survey on the number of firms selling AM inocula in Europe was determined by an internet surveyed. Based on the year of foundation, the number of firms was determined for three time points (year 2000, 2010, 2017).

APPLICATION OF AM TO AGRICULTURAL AND HORTICULTURAL CROPS

With the multiple benefits that AMF confer to their hosts, they hold great promise for application in crop production under various conditions. Most agricultural crops are hosts for AMF and can therefore potentially benefit from inoculation with AMF. Indeed, many studies have shown that application of commercial AMF inoculum benefits crops under agricultural conditions (Weber, 2014). Numerous studies have shown that AMF can increase plant health and yield (Mäder et al., 2000; Rouphael et al., 2015; Hijri, 2016). AMF support plant nutrition by absorbing and translocating mineral nutrients beyond the depletion zones of plant rhizosphere (see above) and induce changes in secondary metabolism leading to improved nutraceutical values. In addition, AMF interfere with the phytohormone balance of host plants, thereby influencing plant development (bioregulators) and inducing tolerance to soil and environmental stresses (bioprotector) (Rouphael et al., 2015). One important aspect of this is the promotion of root system development (Gutjahr and Paszkowski, 2013).

Since the production and application of AM fungal inoculum is relatively labor-intensive, AM application is particularly interesting for high-value crops, e.g., in horticulture, and for the adaptation of cuttings and micro-propagated plantlets in nurseries (AzconAguilar and Barea, 1997; Jeffries et al., 2003; Kleinwächter et al., 2008; Maronek et al., 2011). A large part of the horticultural plant production involves sterile micropropagation *in vitro*. A critical point of development of plantlets generated in this way is the transfer to soil (weaning) that can cause large losses (Schubert and Lubraco, 2000). Inoculation with AMF of micro-propagated fruit trees at transplant improves growth and nutrient uptake during the weaning stage, yielding plants of larger size and improved commercial characteristics (Lovato et al., 1992; Cordier et al., 1996; Schubert and Lubraco, 2000). AM fungi can accelerate this transition and improve the health of the plantlets (Vestberg et al., 2002), thereby rendering plant production more profitable. A good example for such an application are apple and peach cuttings that grow stronger with AM fungal inoculum (Schubert and Lubraco, 2000; Balla et al., 2008).

Arbuscular mycorrhiza inoculation can also be profitable in plant production at a large agricultural scale. A particularly well documented case is a large meta-analysis of potato production in 231 field trials in Europe and North America, which showed a significant increase in tuber production after inoculation with the commercial strain *R. irregularis* (DAOM 197198) (Hijri, 2016). Interestingly, in all these field trials, the farmers themselves carried out the application and evaluation under their respective conventional agricultural practice (including application of pesticides and fertilizers). This approach caused the experimental conditions to be heterogeneous, and the experimental design did not involve replicate plots or randomization. However, the large number of field sites provide robustness to the results, which were remarkably positive. Interestingly, a general beneficial effect was observed independent of location, soil type, experimentor and the details of farming practice (Hijri, 2016). The average yield increase in these 231 field trials amounted to 3.9 tons/ha, representing 9.5% of total crop yield. With an estimated threshold for profitability of 0.67 tons/ha increased yield, nearly 80% of all trials were more profitable thanks to AMF application. This impressive meta-analysis suggests that farmers of potato, and perhaps other crops, can realize significantly increased revenue thanks to AM. In addition, AMF application can allow to decrease the amount of fertilization without a decrease in yield, thereby further increasing profitability. In conclusion, such large-scale trials provide more robust results than more controlled greenhouse or small-scale trials.

Although the application of AM in horticulture and agriculture has great potential, the effectiveness and success of AMF on extended field applications depend to a large degree on external conditions that need to be taken into account. Factors such as plowing and high fertilizer application (in particular P) interfere with AMF abundance and colonization (Douds and Millner, 1999; Mäder et al., 2000; Grant et al., 2005; Hartmann et al., 2015). Other factors that affect AMF symbiosis include the use of specific biocides and cropping with non-host plants (e.g., *Brassicaceae, Chenopodiaceae*) (Njeru et al., 2015). In addition, for every crop, the best corresponding AM fungus should be selected (Rouphael et al., 2015), because AM fungi can provide diverse benefits (growth, stress resistance etc.), and not in each combination of plant and fungus, the trait of interest (e.g., growth) is necessarily positively influenced (Klironomos, 2003) (see above).

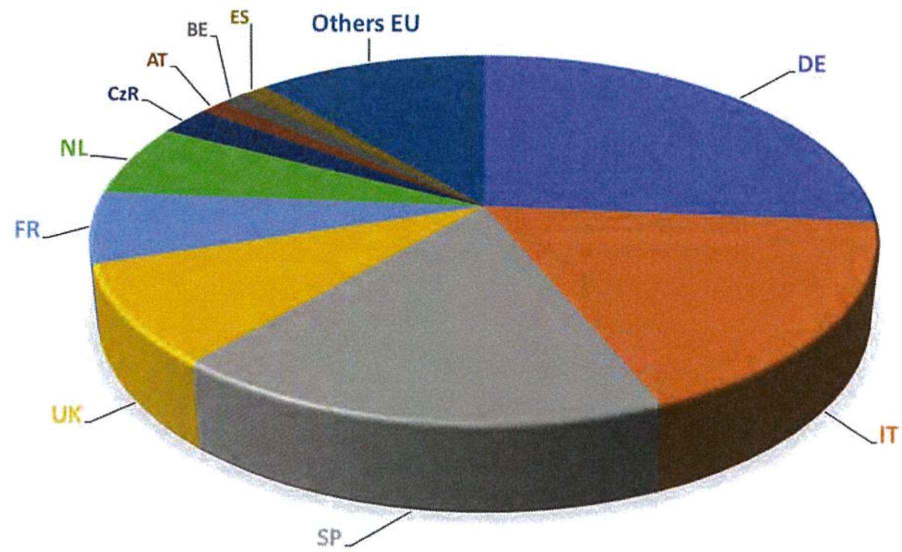

FIGURE 4 | Main players in the AM market in the European Union. The number of companies selling AM inocula is expressed in relation of their location of the main house. Main producer countries are Germany (DE), Italy (IT), Spain (SP), the United Kingdom (UK), France (FR), and the Netherlands (NL).

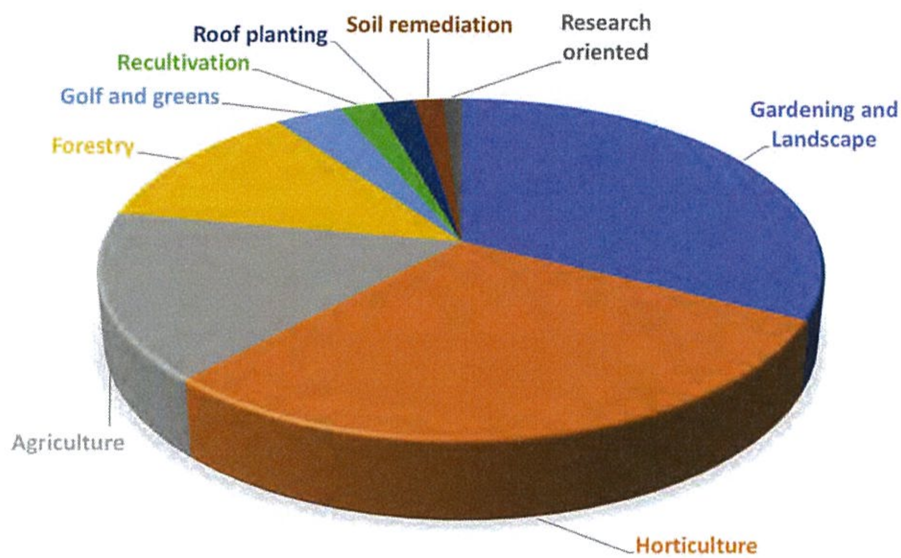

FIGURE 5 | Main domains of application of AM products. The number of products of European firms was determined for each domain of application. Main fields of application are gardening and landscaping, horticulture, agriculture, and forestry.

POTENTIAL FOR THE USE OF AM FUNGI FOR RENATURATION, REFORESTATION, AND LANDSCAPING

Renaturation and afforestation are measures to stabilize degraded and eroding surfaces. In particular in arid regions, young trees are very vulnerable to abiotic stresses (drought, heat, nutrient starvation), in particular at early stages until they have established a deep root system that allows them to access ground water reserves. This critical phase can be overcome with mycorrhizal inoculation of the trees before planting. For example, the Moroccan argan tree, the fruits of which are used to prepare the precious argan oil (El Abbassi et al., 2014), are endangered in their original areas of distribution due to overuse (Lybbert et al., 2011), despite their protection as UNESCO biological reservation[2]. Argan reforestation requires that young plantlets raised in nurseries are planted out, and that they quickly adapt to the dry climate of the native range of these trees. Mycorrhizal inoculation significantly increases the growth and health of

[2]http://www.unesco.org

young argan trees, thereby increasing their fitness and survival after planting (Sellal et al., 2017).

A similar case is represented by the use of a mixture of indigenous AM fungi for the inoculation of young Cypress trees (*Cupressus atlantica*) (Ouahmane et al., 2007). In this study, only AM fungi isolated from the natural site of *C. atlantica* were used, thereby increasing the chances to employ fungi that are well adapted to drought and to *C. atlantica*, and avoiding to introduce new AM fungal species with unpredictable effects on the local environment. AM inoculation not only increased plant growth, but also increased survival of the trees in the dry native conditions. This latter point is perhaps even more important than the growth promotion, because it renders reforestation efforts more sustainable.

Another interesting example is stabilizing sand dunes by planting of the drought-tolerant mesquite tree (*Prosopis juliflora*), which increases mycorrhizal communities in sand dunes (Moradi et al., 2017). On the other hand, the mesquite trees profit from AM colonization (Solis-Dominguez et al., 2011). Hence, AM symbiosis can be a critical component in strategies to protect vulnerable sandy soils against erosion, and to improve their fertility.

CAN AM FUNGI PROMOTE BIOREMEDIATION OF CONTAMINATED SOILS?

During the last decades, the potential of plants has been explored to reduce the contamination of soils polluted by organic compounds or heavy metals, and AM fungi could potentially play a central role in such strategies (Leyval et al., 2002; Turnau et al., 2006; Khade and Adholeya, 2007; Sheoran et al., 2010). Thanks to their mineral-scavenging capacities, and with their protective role against abiotic stress, AM fungi can potentially promote plant growth in contaminated soils, a capacity commonly referred to as bioremediation (Leyval et al., 2002; Göhre and Paszkowski, 2006). They can do so in two ways: they can either accumulate and sequester toxic metal ions, thereby protecting their host from the pollutant (Weissenhorn et al., 1995; Diaz et al., 1996; Gonzalez-Chavez et al., 2004), or they can deliver them to the host just like essential mineral nutrients such as Cu and Zn, resulting in heavy metal accumulation in the host. In the first case, plant production can be enabled in polluted substrate, with minimal contamination of the crop. In the second case, the plants can be harvested and destroyed to reduce the heavy metal load of the site (phytoextraction) (Burns et al., 1996; Khan et al., 2000). Of course, both approaches require heavy-metal-tolerant AM fungi, and phytoextraction in addition requires highly tolerant host plants that can cope with toxic heavy metals, and at the same time yield large shoot biomass in order to accumulate significant amounts of heavy metals.

To date numerous laboratory studies have been carried out to explore the potential of AM in bioremediation of the soil, however, only few field studies have addressed the applicability of this approach to large scale conditions (Burns et al., 1996; Adriano et al., 2004; Chibuike, 2013). Worldwide, there are only few companies offering AM fungal products for bioremediation. Some of the obstacles include the fact that most heavy metal-accumulating plants are rather small, and some are not host plants for AM fungi (e.g., the crucifer *Thlaspi*). In addition, AM colonization is often reduced by high pollution.

CAN AM FUNGI BE BRED FOR IMPROVED SYMBIOTIC TRAITS?

Given the promising features, but also the limitations of AM fungi for application in plant production, it would be a great asset if they could be bred for higher efficiency in the respective context of interest. Classical breeding (by crossing and selection in the progeny of variants with new desired features) is currently impossible with AM fungi owing to their particular genetic constitution (Sanders and Croll, 2010). Their syncytial nature and their purely clonal propagation, as well as the absence of recognizable sexual stages prevents forward and reverse genetic approaches such as mutant screening, transformation, crossing, genetic mapping etc.. However, the mycelia of AM fungi can fuse by a process known as anastomosis, which allows for the exchange of genetic material (incl. nuclei) between the two syncytia (Giovannetti et al., 1999).

"Crossing" of AM fungi by anastomosis, and subsequent culturing of AM fungal progeny can generate new genotypes with new symbiotic features (Angelard et al., 2010; Angelard and Sanders, 2011). In particular, new beneficial mycorrhizal traits can result from this kind of breeding scheme (Angelard et al., 2010). However, anastomosis is only possible between compatible AM fungal isolates of the same, or perhaps closely related species (de Novais et al., 2017), indicating that it requires genetic compatibility factors. Based on these findings, AM fungi could potentially be bred for improved symbiotic traits by systematic genetic reshuffling between divergent (but compatible) AM fungal isolates, followed by screening for the most beneficial new strains among AM fungal segregants. This screening should be performed with each host plant of interest, thus allowing to identify the best-suited AM fungal segregant for each target host species. Such combinations could subsequently further evolve by continued selection for improved AM fungal descendants with more beneficial effects on the host plant. Such changes can emerge surprisingly quickly, possibly driven by genetic drift among the heterogeneous nucleotypes of the expanding syncytial AM fungal mycelium (Angelard et al., 2014).

FUTURE OPPORTUNITIES AND CHALLENGES FOR AMF

Inspite of its growing trend, the current market for mycorrhizal products remains far from its full potential. Apart from technical issues, challenges for AM fungal products in the coming years include (i) political and regulatory constraints; (ii) quality assurance and product efficacy; and (iii) customer awareness and acceptance.

In terms of regulations and policies, the current market for mycorrhizal products has, to date, remained relatively unrestricted by political forces. In Europe, there is no unifying regulation covering (and controlling) the manufacture, use or movement of mycorrhizal fungal products (Vosatka et al., 2008). Depending on their intended use, AM fungal products could be registered in the market in three different categories: as bioprotectants, as biofertilizers, or as biostimulants. The registration has to be performed according to the national regulations of each EU state member. In some cases (e.g., France and Belgium), the regulatory process is quite complex and expensive. Such regulations result in limitations and market entry barriers for AM fungal products (Vosatka et al., 2008). In this regard, the European Parliament is currently evaluating the establishment of an equitable EU market for biostimulants. The key elements considered by the EU to establish a single-market include: defining biostimulants and defining the boundary with plant protection products; the requirement to develop safety criteria and harmonized standards, in particular for microorganisms, and promoting a circular economy with the efficient use of plants and plant extracts. A single harmonized market for biostimulants will support EU farmers to become more competitive and participate in developing sustainable agriculture with a reduced impact on the environment.

In relation to product quality, given the lack of regulatory bodies to set the quality parameters, AMF producers rely on self-imposed quality standards to ensure best practice in production (Vosatka et al., 2008). In Europe, for instance, the main AMF producers have agreed on the use of a protocol proposed by Gianinazzi-Pearson et al. (1985) to define quality of AMF products. This protocol is known as the "most probable number" (MPN) and serves to determine the presence or absence of AMF in a dilution series, with the results interpreted as a probability estimate of propagule number from a statistical table. Even though the assay is indirect (absolute numbers of propagules are not measured), it has the advantage of providing a single number that can be compared directly with other tests in the same assay. However, other qualitative parameters should also be taken into account, in particular richness of inoculum (number of spores or propagules/ml) and infectivity, i.e., the capacity of the inoculum to establish mycorrhizal symbiosis. Finally, not every combination of a plant and an AM fungus is beneficial (see above), hence, it is advisable to test different AM inocula for each crop of interest to identify optimal combinations of plant and AMF.

In general, product quality and efficiency are still areas that require further attention. The appropriate dosage, or propagule density, for a given market sector is not yet formalized and it leaves scope for the marketers to set these values. The aforementioned constraints open a window of opportunity for the research community in order to assist producers and the market in defining what should be the minimum treatment standard (Vosatka et al., 2008). Other critical challenges for the AM market are customer awareness and acceptance. Although the use of biostimulants and biofertilizers is growing in popularity, the use of traditional chemical fertilizer products remains as the most common practice among farmers. In this respect, AMF producers are focusing their efforts to establish relevant case studies and field trials to demonstrate and prove the benefits of AMF in agriculture and horticulture. Larger organisms contributing to the promotion of biostimulants include the The European Biostimulant Industry Council (EBIC[3]), and the International Mycorrhiza Society (IMS[4]).

OUTLOOK

Arbuscular mycorrhizal fungi promote many aspects of plant life, in particular improved nutrition, better growth, stress tolerance, and disease resistance. In addition, the hyphal networks of AM fungi improve soil characters such as soil particle aggregation thereby improving the resistance of soil toward erosion by wind and water. Finally, AM fungi decrease nutrient leaching from the soil, thereby contributing to the retention of nutrients in the soil, and decreasing the risks of contamination of ground water. These multiple benefits of AM fungi translate into significant ecological services in natural contexts. The promises for agriculture have been clearly documented for certain crops, in particular potato, however, many applications have still to be developed, which requires significant investment in research and development of AM fungal inocula suited for additional crops.

AUTHOR CONTRIBUTIONS

MC, MA, LB, and EN contributed significant parts of the text. DR was the main coordinator and wrote a large part of the manuscript.

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[3] http://www.biostimulants.eu

[4] http://mycorrhizas.org

REFERENCES

Adriano, D. C., Wenzel, W. W., Vangronsveld, J., and Bolan, N. S. (2004). Role of assisted natural remediation in environmental cleanup. *Geoderma* 122, 121–142. doi: 10.1016/j.geoderma.2004.01.003

Akiyama, K., Matsuzaki, K., and Hayashi, H. (2005). Plant sesquiterpenes induce hyphal branching in arbuscular mycorrhizal fungi. *Nature* 435, 824–827. doi: 10.1038/nature03608

Alexander, T., Toth, R., Meier, R., and Weber, H. C. (1989). Dynamics of arbuscule development and degeneration in onion, bean, and tomato with reference to vesicular-arbuscular mycorrhizae in grasses. *Can. J. Bot-Rev. Can. Bot.* 67, 2505–2513. doi: 10.1139/b89-320

Al-Yahya'ei, M., Oehl, F., Vallino, M., Lumini, E., Redecker, D., Wiemken, A., et al. (2011). Unique arbuscular mycorrhizal fungal communities uncovered in date palm plantations and surrounding desert habitats of Southern Arabia. *Mycorrhiza* 21, 195–209. doi: 10.1007/s00572-010-0323-5

Angelard, C., Colard, A., Niculita-Hirzel, H., Croll, D., and Sanders, I. R. (2010). Segregation in a mycorrhizal fungus alters rice growth and symbiosis-specific gene transcription. *Curr. Biol.* 20, 1216–1221. doi: 10.1016/j.cub.2010.05.031

Angelard, C., and Sanders, I. R. (2011). Effect of segregation and genetic exchange on arbuscular mycorrhizal fungi in colonization of roots. *New Phytol.* 189, 652–657. doi: 10.1111/j.1469-8137.2010.03602.x

Angelard, C., Tanner, C. J., Fontanillas, P., Niculita-Hirzel, H., Masclaux, F., and Sanders, I. R. (2014). Rapid genotypic change and plasticity in arbuscular mycorrhizal fungi is caused by a host shift and enhanced by segregation. *ISME J.* 8, 284–294. doi: 10.1038/ismej.2013.154

Augé, R. M. (2001). Water relations, drought and vesicular-arbuscular mycorrhizal symbiosis. *Mycorrhiza* 11, 3–42. doi: 10.1007/s005720100097

AzconAguilar, C., and Barea, J. M. (1997). Applying mycorrhiza biotechnology to horticulture: significance and potentials. *Sci. Hortic.* 68, 1–24. doi: 10.1016/S0304-4238(96)00954-5

Balla, I., Szucs, E., Borkowska, B., and Michalczuk, B. (2008). "Evaluation the response of micropropagated peach and apple rootstocks to different mycorrhizal inocula," in *Mycorrhiza Works*, eds F. Feldmann, Y. Kapulnik, and J. Baar (Braunschweig: Deutsche Phytomedizinische Gesellschaft), 126–134.

Besserer, A., Puech-Pagès, V., Kiefer, P., Gomez-Roldan, V., Jauneau, A., Roy, S., et al. (2006). Strigolactones stimulate arbuscular mycorrhizal fungi by activating mitochondria. *PLoS Biol.* 4, 1239–1247. doi: 10.1371/journal.pbio.0040226

Bever, J. D. (2002). Host-specificity of AM fungal population growth rates can generate feedback on plant growth. *Plant Soil* 244, 281–290. doi: 10.1023/A:1020221609080

Bidartondo, M. I. (2005). The evolutionary ecology of myco-heterotrophy. *New Phytol.* 167, 335–352. doi: 10.1111/j.1469-8137.2005.01429.x

Bidartondo, M. I., Read, D. J., Trappe, J. M., Merckx, V., Ligrone, R., and Duckett, J. G. (2011). The dawn of symbiosis between plants and fungi. *Biol. Lett.* 7, 574–577. doi: 10.1098/rsbl.2010.1203

Bidartondo, M. I., Redecker, D., Hijri, I., Wiemken, A., Bruns, T. D., Dominguez, L., et al. (2002). Epiparasitic plants specialized on arbuscular mycorrhizal fungi. *Nature* 419, 389–392. doi: 10.1038/nature01054

Bitterlich, M., Sandmann, M., and Graefe, J. (2018). Arbuscular mycorrhiza alleviates restrictions to substrate water flow and delays transpiration limitation to stronger drought in tomato. *Front.Plant Sci.* 9:154. doi: 10.3389/fpls.2018.00154

Boldt, K., Pors, Y., Haupt, B., Bitterlich, M., Kuhn, C., Grimm, B., et al. (2011). Photochemical processes, carbon assimilation and RNA accumulation of sucrose transporter genes in tomato arbuscular mycorrhiza. *J. Plant Physiol.* 168, 1256–1263. doi: 10.1016/j.jplph.2011.01.026

Boller, T., and Felix, G. (2009). A renaissance of elicitors: perception of microbe-associated molecular patterns and danger signals by pattern-recognition receptors. *Annu. Rev. Plant Biol.* 60, 379–406. doi: 10.1146/annurev.arplant.57.032905.105346

Borowicz, V. A. (2001). Do arbuscular mycorrhizal fungi alter plant-pathogen relations? *Ecology* 82, 3057–3068.

Brands, M., Wewer, V., Keymer, A., Gutjahr, C., and Doermann, P. (2018). The *Lotus japonicus* acyl-acyl carrier protein thioesterase FatM is required for mycorrhiza formation and lipid accumulation of *Rhizophagus irregularis*. *Plant J.* 95, 219–232. doi: 10.1111/tpj.13943

Bravo, A., Brands, M., Wewer, V., Doermann, P., and Harrison, M. J. (2017). Arbuscular mycorrhiza-specific enzymes FatM and RAM2 fine-tune lipid biosynthesis to promote development of arbuscular mycorrhiza. *New Phytol.* 214, 1631–1645. doi: 10.1111/nph.14533

Breuillin, F., Schramm, J., Hajirezaei, M., Ahkami, A., Favre, P., Druege, U., et al. (2010). Phosphate systemically inhibits development of arbuscular mycorrhiza in *Petunia hybrida* and represses genes involved in mycorrhizal functioning. *Plant J.* 64, 1002–1017. doi: 10.1111/j.1365-313X.2010.04385.x

Brundrett, M. (2004). Diversity and classification of mycorrhizal associations. *Biol. Rev.* 79, 473–495. doi: 10.1017/S1464793103006316

Brundrett, M. C. (2002). Coevolution of roots and mycorrhizas of land plants. *New Phytol.* 154, 275–304. doi: 10.1046/j.1469-8137.2002.00397.x

Bunn, R., Lekberg, Y., and Zabinski, C. (2009). Arbuscular mycorrhizal fungi ameliorate temperature stress in thermophilic plants. *Ecology* 90, 1378–1388. doi: 10.1890/07-2080.1

Burns, R. G., Rogers, S. L., and McGhee, I. (1996). "Remediation of inorganics and organics in industrial and urban contaminated soils," in *Contaminants and the Soil Environment in the Australia Pacific region*, eds R. Naidu, R. S. Kookana, D. P. Oliver, and M. J. McLaughlin (London: Kluwer Academic Publishers), 361–410.

Calabrese, S., Kohler, A., Niehl, A., Veneault-Fourrey, C., Boller, T., and Courty, P. E. (2017). Transcriptome analysis of the *Populus trichocarpa-Rhizophagus irregularis* mycorrhizal symbiosis: regulation of plant and fungal transportomes under nitrogen starvation. *Plant Cell Physiol.* 58, 1003–1017. doi: 10.1093/pcp/pcx044

Cameron, D. D., Neal, A. L., van Wees, S. C. M., and Ton, J. (2013). Mycorrhiza-induced resistance: more than the sum of its parts? *Trends Plant Sci.* 18, 539–545. doi: 10.1016/j.tplants.2013.06.004

Cameron, K. C., Di, H. J., and Moir, J. L. (2013). Nitrogen losses from the soil/plant system: a review. *Ann. Appl. Biol.* 162, 145–173. doi: 10.1111/aab.12014

Cavagnaro, T. R., Bender, S. F., Asghari, H. R., and van der Heijden, M. G. A. (2015). The role of arbuscular mycorrhizas in reducing soil nutrient loss. *Trends Plant Sci.* 20, 283–290. doi: 10.1016/j.tplants.2015.03.004

Chagnon, P.-L. (2014). Ecological and evolutionary implications of hyphal anastomosis in arbuscular mycorrhizal fungi. *FEMS Microbiol. Ecol.* 88, 437–444. doi: 10.1111/1574-6941.12321

Chen, E. C. H., Morin, E., Beaudet, D., Noel, J., Yildirir, G., Ndikumana, S., et al. (2018). High intraspecific genome diversity in the model arbuscular mycorrhizal symbiont Rhizophagus irregularis. *New Phytol.* [Epub ahead of print]. doi: 10.1111/nph.14989

Chibuike, G. U. (2013). Use of mycorrhiza in soil remediation: a review. *Sci. Res. Essays* 8, 1697–1687. doi: 10.5897/SRE2013.5605

Chitarra, W., Pagliarani, C., Maserti, B., Lumini, E., Siciliano, I., Cascone, P., et al. (2016). Insights on the impact of arbuscular mycorrhizal symbiosis on tomato tolerance to water stress. *Plant Physiol.* 171, 1009–1023. doi: 10.1104/pp.16.00307

Clark, R. B., and Zeto, S. K. (2000). Mineral acquisition by arbuscular mycorrhizal plants. *J. Plant Nutr.* 23, 867–902. doi: 10.1080/01904160009382068

Conrath, U., Beckers, G. J. M., Flors, V., Garcia-Agustin, P., Jakab, G., Mauch, F., et al. (2006). Priming: getting ready for battle. *Mol. Plant-Microbe Interact.* 19, 1062–1071. doi: 10.1094/MPMI-19-1062

Cordier, C., Trouvelot, A., Gianinazzi, S., and GianinazziPearson, V. (1996). Arbuscular mycorrhiza technology applied to micropropagated *Prunus avium* and to protection against *Phytophthora cinnamomi*. *Agronomie* 16, 679–688. doi: 10.1051/agro:19961013

Dangeard, P. A. (1900). Le "*Rhizophagus populinus*" Dangeard. *Le Botaniste* 7, 285–291.

de Novais, C. B., Pepe, A., Siqueira, J. O., Giovannetti, M., and Sbrana, C. (2017). Compatibility and incompatibility in hyphal anastomosis of arbuscular mycorrhizal fungi. *Sci. Agric.* 74, 411–416. doi: 10.1590/1678-992x-2016-0243

de Vries, J., and Archibald, J. M. (2018). Plant evolution: landmarks on the path to terrestrial life. *New Phytol.* 217, 1428–1434. doi: 10.1111/nph.14975

Delaux, P. M. (2017). Comparative phylogenomics of symbiotic associations. *New Phytol.* 213, 89–94. doi: 10.1111/nph.14161

Delwiche, C. F., and Cooper, E. D. (2015). The evolutionary origin of a terrestrial flora. *Curr. Biol.* 25, R899–R910. doi: 10.1016/j.cub.2015.08.029

Diaz, G., AzconAguilar, C., and Honrubia, M. (1996). Influence of arbuscular mycorrhizae on heavy metal (Zn and Pb) uptake and growth of *Lygeum spartum* and *Anthyllis cytisoides*. *Plant Soil* 180, 241–249. doi: 10.1007/BF00015307

Douds, D. D., and Millner, P. (1999). Biodiversity of arbuscular mycorrhizal fungi in agroecosystems. *Agric. Ecosyst. Environ.* 74, 77–93. doi: 10.1016/S0167-8809(99)00031-6

El Abbassi, A., Khalid, N., Zbakh, H., and Ahmad, A. (2014). Physicochemical characteristics, nutritional properties, and health benefits of argan oil: a review. *Crit. Rev. Food Sci. Nutr.* 54, 1401–1414. doi: 10.1080/10408398.2011.638424

Field, K. J., Pressel, S., Duckett, J. G., Rimington, W. R., and Bidartondo, M. I. (2015). Symbiotic options for the conquest of land. *Trends Ecol. Evol.* 30, 477–486. doi: 10.1016/j.tree.2015.05.007

Fiorilli, V., Catoni, M., Miozzi, L., Novero, M., Accotto, G. P., and Lanfranco, L. (2009). Global and cell-type gene expression profiles in tomato plants colonized by an arbuscular mycorrhizal fungus. *New Phytol.* 184, 975–987. doi: 10.1111/j.1469-8137.2009.03031.x

Gaude, N., Bortfeld, S., Duensing, N., Lohse, M., and Krajinski, F. (2012). Arbuscule-containing and non-colonized cortical cells of mycorrhizal roots undergo extensive and specific reprogramming during arbuscular mycorrhizal development. *Plant J.* 69, 510–528. doi: 10.1111/j.1365-313X.2011.04810.x

Genre, A., Chabaud, M., Faccio, A., Barker, D. G., and Bonfante, P. (2008). Prepenetration apparatus assembly precedes and predicts the colonization patterns of arbuscular mycorrhizal fungi within the root cortex of both *Medicago truncatula* and *Daucus carota*. *Plant Cell* 20, 1407–1420. doi: 10.1105/tpc.108.059014

Genre, A., Chabaud, M., Timmers, T., Bonfante, P., and Barker, D. G. (2005). Arbuscular mycorrhizal fungi elicit a novel intracellular apparatus in *Medicago truncatula* root epidermal cells before infection. *Plant Cell* 17, 3489–3499. doi: 10.1105/tpc.105.035410

George, E. (2000). "Nutrient uptake – Contributions of arbuscular mycorrhizal fungi to plant mineral nutrition," in *Arbuscular Mycorrhizas: Physiology and Function*, eds Y. Kapulnik and D. D. Douds (Dordrecht: Kluwer Academic Publishers), 307–343.

Gianinazzi-Pearson, V., Gianinazzi, S., and Trouvelot, A. (1985). Evaluation of the infectivity and effectiveness of indigenous vesicular arbuscular fungal populations in some agricultural soils in Burgundy. *Can. J. Bot-Rev. Can. Bot.* 63, 1521–1524. doi: 10.1139/b85-210

Giovannetti, M., Azzolini, D., and Citernesi, A. S. (1999). Anastomosis formation and nuclear and protoplasmic exchange in arbuscular mycorrhizal fungi. *Appl. Environ. Microbiol.* 65, 5571–5575.

Göhre, V., and Paszkowski, U. (2006). Contribution of the arbuscular mycorrhizal symbiosis to heavy metal phytoremediation. *Planta* 223, 1115–1122. doi: 10.1007/s00425-006-0225-0

Gomez, S. K., Javot, H., Deewatthanawong, P., Torres-Jerez, I., Tang, Y. H., Blancaflor, E. B., et al. (2009). *Medicago truncatula* and *Glomus intraradices* gene expression in cortical cells harboring arbuscules in the arbuscular mycorrhizal symbiosis. *BMC Plant Biol.* 9:10. doi: 10.1186/1471-2229-9-10

Gonzalez-Chavez, M. C., Carrillo-Gonzalez, R., Wright, S. F., and Nichols, K. A. (2004). The role of glomalin, a protein produced by arbuscular mycorrhizal fungi, in sequestering potentially toxic elements. *Environ. Pollut.* 130, 317–323. doi: 10.1016/j.envpol.2004.01.004

Graham, S. W., Lam, V. K. Y., and Merckx, V. (2017). Plastomes on the edge: the evolutionary breakdown of mycoheterotroph plastid genomes. *New Phytol.* 214, 48–55. doi: 10.1111/nph.14398

Grant, C., Bittman, S., Montreal, M., Plenchette, C., and Morel, C. (2005). Soil and fertilizer phosphorus: effects on plant P supply and mycorrhizal development. *Can. J. Plant Sci.* 85, 3–14. doi: 10.4141/P03-182

Guether, M., Balestrini, R., Hannah, M., He, J., Udvardi, M., and Bonfante, P. (2009). Genome-wide reprogramming of regulatory networks, cell wall and membrane biogenesis during arbuscular-mycorrhizal symbiosis in *Lotus japonicus*. *New Phytol.* 182, 200–212. doi: 10.1111/j.1469-8137.2008.02725.x

Güimil, S., Chang, H. S., Zhu, T., Sesma, A., Osbourn, A., Roux, C., et al. (2005). Comparative transcriptomics of rice reveals an ancient pattern of response to microbial colonization. *Proc. Natl. Acad. Sci. U.S.A.* 102, 8066–8070. doi: 10.1073/pnas.0502999102

Gutjahr, C., and Parniske, M. (2013). Cell and developmental biology of arbuscular mycorrhiza symbiosis. *Annu. Rev. Cell Dev. Biol.* 29, 593–617. doi: 10.1146/annurev-cellbio-101512-122413

Gutjahr, C., and Paszkowski, U. (2013). Multiple control levels of root system remodeling in arbuscular mycorrhizal symbiosis. *Front. Plant Sci.* 4:204. doi: 10.3389/fpls.2013.00204

Guttenberger, M. (2000). Arbuscules of vesicular-arbuscular mycorrhizal fungi inhabit an acidic compartment within plant roots. *Planta* 211, 299–304. doi: 10.1007/s004250000324

Harrison, M. J. (2012). Cellular programs for arbuscular mycorrhizal symbiosis. *Curr. Opin. Plant Biol.* 15, 691–698. doi: 10.1016/j.pbi.2012.08.010

Harrison, M. J., Dewbre, G. R., and Liu, J. Y. (2002). A phosphate transporter from *Medicago truncatula* involved in the acquisiton of phosphate released by arbuscular mycorrhizal fungi. *Plant Cell* 14, 2413–2429. doi: 10.1105/tpc.004861

Hartmann, M., Frey, B., Mayer, J., Mader, P., and Widmer, F. (2015). Distinct soil microbial diversity under long-term organic and conventional farming. *ISME J.* 9, 1177–1194. doi: 10.1038/ismej.2014.210

Heckman, D. S., Geiser, D. M., Eidell, B. R., Stauffer, R. L., Kardos, N. L., and Hedges, S. B. (2001). Molecular evidence for the early colonization of land by fungi and plants. *Science* 293, 1129–1133. doi: 10.1126/science.1061457

Hijri, M. (2016). Analysis of a large dataset of mycorrhiza inoculation field trials on potato shows highly significant increases in yield. *Mycorrhiza* 26, 209–214. doi: 10.1007/s00572-015-0661-4

Hogekamp, C., and Küster, H. (2013). A roadmap of cell-type specific gene expression during sequential stages of the arbuscular mycorrhiza symbiosis. *BMC Genomics* 14:306. doi: 10.1186/1471-2164-14-306

Hohnjec, N., Vieweg, M. E., Puhler, A., Becker, A., and Küster, H. (2005). Overlaps in the transcriptional profiles of *Medicago truncatula* roots inoculated with two different Glomus fungi provide insights into the genetic program activated during arbuscular mycorrhiza. *Plant Physiol.* 137, 1283–1301. doi: 10.1104/pp.104.056572

Husband, R., Herre, E. A., Turner, S. L., Gallery, R., and Young, J. P. W. (2002). Molecular diversity of arbuscular mycorrhizal fungi and patterns of host association over time and space in a tropical forest. *Mol. Ecol.* 11, 2669–2678. doi: 10.1046/j.1365-294X.2002.01647.x

Jacott, C. N., Murray, J. D., and Ridout, C. J. (2017). Trade-offs in arbuscular mycorrhizal symbiosis: disease resistance, growth responses and perspectives for crop breeding. *Agronormy* 7:75. doi: 10.3390/agronomy7040075

Jakobsen, I., and Hammer, E. C. (2015). "Nutrient dynamics in arbuscular mycorrhizal networks," in *Mycorrhizal Networks*, ed. T. R. Horton (Dordrecht: Springer), 91–131. doi: 10.1007/978-94-017-7395-9_4

Jeffries, P., Gianinazzi, S., Perotto, S., Turnau, K., and Barea, J. M. (2003). The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. *Biol. Fertil Soils* 37, 1–16.

Jiang, Y., Wang, W., Xie, Q., Liu, N., Liu, L., Wang, D., et al. (2017). Plants transfer lipids to sustain colonization by mutualistic mycorrhizal and parasitic fungi. *Science* 356, 1172–1175. doi: 10.1126/science.aam9970

Jung, S. C., Martinez-Medina, A., Lopez-Raez, J. A., and Pozo, M. J. (2012). Mycorrhiza-induced resistance and priming of plant defenses. *J. Chem. Ecol.* 38, 651–664. doi: 10.1007/s10886-012-0134-6

Kamel, L., Tang, N. W., Malbreil, M., San Clemente, H., Le Marquer, M., Roux, C., et al. (2017). The comparison of expressed candidate secreted proteins from two arbuscular mycorrhizal fungi unravels common and specific molecular tools to invade different host plants. *Front. Plant Sci.* 8:124. doi: 10.3389/fpls.2017.00124

Karandashov, V., and Bucher, M. (2005). Symbiotic phosphate transport in arbuscular mycorrhizas. *Trends Plant Sci.* 10, 22–29. doi: 10.1016/j.tplants.2004.12.003

Keymer, A., Pimprikar, P., Wewer, V., Huber, C., Brands, M., Bucerius, S. L., et al. (2017). Lipid transfer from plants to arbuscular mycorrhiza fungi. *Elife* 6:e29107. doi: 10.7554/eLife.29107

Khade, S. W., and Adholeya, A. (2007). Feasible bioremediation through arbuscular mycorrhizal fungi imparting heavy metal tolerance: a retrospective. *Bioremed. J.* 11, 33–43. doi: 10.1080/10889860601185855

Khan, A. G., Kuek, C., Chaudhry, T. M., Khoo, C. S., and Hayes, W. J. (2000). Role of plants, mycorrhizae and phytochelators in heavy metal contaminated land remediation. *Chemosphere* 41, 197–207. doi: 10.1016/S0045-6535(99)00412-9

Kiers, E. T., and Denison, R. F. (2008) Sanctions, cooperation, and the stability of plant-rhizosphere mutualisms. *Annu. Rev. Ecol. Evol. Syst.* 39, 215–236. doi: 10.1146/annurev.ecolsys.39.110707.173423

Kleinwächter, M., Hutter, I., Schneider, C., Schnug, E., and Selmar, D. (2008). Experimental field cultivation of in vitro propagated high-yield varieties of *Tropaeolum majus* L. *J. Appl. Bot. Food Qual. Angew. Botanik* 82, 55–59.

Klironomos, J. N. (2003). Variation in plant response to native and exotic arbuscular mycorrhizal fungi. *Ecology* 84, 2292–2301. doi: 10.1890/02-0413

Kloppholz, S., Kuhn, H., and Requena, N. (2011). A secreted fungal effector of *Glomus intraradices* promotes symbiotic biotrophy. *Curr. Biol.* 21, 1204–1209. doi: 10.1016/j.cub.2011.06.044

Krajinski, F., Courty, P. E., Sieh, D., Franken, P., Zhang, H. Q., Bucher, M., et al. (2014). The H+-ATPase HA1 of *Medicago truncatula* is essential for phosphate transport and plant growth during arbuscular mycorrhizal symbiosis. *Plant Cell* 26, 1808–1817. doi: 10.1105/tpc.113.120436

Kretzschmar, T., Kohlen, W., Sasse, J., Borghi, L., Schlegel, M., Bachelier, J. B., et al. (2012). A petunia ABC protein controls strigolactone-dependent symbiotic signalling and branching. *Nature* 483, 341–346. doi: 10.1038/nature10873

Lee, E. H., Eo, J. K., Ka, K. H., and Eom, A. H. (2013). Diversity of arbuscular mycorrhizal fungi and their roles in ecosystems. *Mycobiology* 41, 121–125. doi: 10.5941/MYCO.2013.41.3.121

Leifheit, E. F., Veresoglou, S. D., Lehmann, A., Morris, E. K., and Rillig, M. C. (2014). Multiple factors influence the role of arbuscular mycorrhizal fungi in soil aggregation-a meta-analysis. *Plant Soil* 374, 523–537. doi: 10.1007/s11104-013-1899-2

Leyval, C., Joner, E. J., del Val, C., and Haselwandter, K. (2002). "Potential of arbuscular mycorrhizal fungi for bioremediation," in *Mycorrhizal Technology in Agriculture*, eds S. Gianinazzi, H. Schiüepp, and J. M. Barea, and K. Haselwandter (Basel: Birkhäuser).

Liu, G. W., Pfeifer, J., Francisco, R. D., Emonet, A., Stirnemann, M., Gubeli, C., et al. (2018). Changes in the allocation of endogenous strigolactone improve plant biomass production on phosphate-poor soils. *New Phytol.* 217, 784–798. doi: 10.1111/nph.14847

Liu, J. Y., Blaylock, L. A., Endre, G., Cho, J., Town, C. D., VandenBosch, K. A., et al. (2003). Transcript profiling coupled with spatial expression analyses reveals genes involved in distinct developmental stages of an arbuscular mycorrhizal symbiosis. *Plant Cell* 15, 2106–2123. doi: 10.1105/tpc.014183

Liu, Y. J., He, J. X., Shi, G. X., An, L. Z., Öpik, M., and Feng, H. Y. (2011). Diverse communities of arbuscular mycorrhizal fungi inhabit sites with very high altitude in Tibet Plateau. *FEMS Microbiol. Ecol.* 78, 355–365. doi: 10.1111/j.1574-6941.2011.01163.x

Lovato, P., Guillemin, J. P., and Gianinazzi, S. (1992). Application of commercial arbuscular endomycorrhizal fungal inoculants to the establishment of micropropagated grapevine rootstock and pineapple plants. *Agronomie* 12, 873–880. doi: 10.1051/agro:19921024

Lovelock, C. E., Andersen, K., and Morton, J. B. (2003). Arbuscular mycorrhizal communities in tropical forests are affected by host tree species and environment. *Oecologia* 135, 268–279. doi: 10.1007/s00442-002-1166-3

Luginbuehl, L. H., Menard, G. N., Kurup, S., Van Erp, H., Radhakrishnan, G. V., Breakspear, A., et al. (2017). Fatty acids in arbuscular mycorrhizal fungi are synthesized by the host plant. *Science* 356, 1175–1178. doi: 10.1126/science.aan0081

Lybbert, T. J., Aboudrare, A., Chaloud, D., Magnan, N., and Nash, M. (2011). Booming markets for Moroccan argan oil appear to benefit some rural households while threatening the endemic argan forest. *Proc. Natl. Acad. Sci. U.S.A.* 108, 13963–13968. doi: 10.1073/pnas.1106382108

MacLean, A. M., Bravo, A., and Harrison, M. J. (2017). Plant signaling and metabolic pathways enabling arbuscular mycorrhizal symbiosis. *Plant Cell* 29, 2319–2335. doi: 10.1105/tpc.17.00555

Mäder, P., Edenhofer, S., Boller, T., Wiemken, A., and Niggli, U. (2000). Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation. *Biol. Fertil. Soils* 31, 150–156. doi: 10.1007/s003740050638

Maronek, D. M., Hendrix, J. W., and Kiernan, J. (2011). "Mycorrhizal fungi and their importance in horticultural crop production on horticultural reviews," in *Horticultural Reviews*, ed. J. Jannick (Westport, CT: The AVI Publishing Company, Inc.).

Moradi, M., Naji, H. R., Imani, F., Behbahani, S. M., and Ahmadi, M. T. (2017). Arbuscular mycorrhizal fungi changes by afforestation in sand dunes. *J. Arid Environ.* 140, 14–19. doi: 10.1016/j.jaridenv.2017.01.006

Munkvold, L., Kjoller, R., Vestberg, M., Rosendahl, S., and Jakobsen, I. (2004). High functional diversity within species of arbuscular mycorrhizal fungi. *New Phytol.* 164, 357–364. doi: 10.1111/j.1469-8137.2004.01169.x

Njeru, E. M., Avio, L., Bocci, G., Sbrana, C., Turrini, A., Barberi, P., et al. (2015). Contrasting effects of cover crops on 'hot spot' arbuscular mycorrhizal fungal communities in organic tomato. *Biol. Fertil. Soils* 51, 151–166. doi: 10.1007/s00374-014-0958-z

Öpik, M., Moora, M., Liira, J., and Zobel, M. (2006). Composition of root-colonizing arbuscular mycorrhizal fungal communities in different ecosystems around the globe. *J. Ecol.* 94, 778–790. doi: 10.1111/j.1365-2745.2006.01136.x

Öpik, M., Zobel, M., Cantero, J. J., Davison, J., Facelli, J. M., Hiiesalu, I., et al. (2013). Global sampling of plant roots expands the described molecular diversity of arbuscular mycorrhizal fungi. *Mycorrhiza* 23, 411–430. doi: 10.1007/s00572-013-0482-2

Ouahmane, L., Hafidi, M., Thioulouse, J., Ducousso, M., Kisa, M., Prin, Y., et al. (2007). Improvement of *Cupressus atlantica* Gaussen growth by inoculation with native arbuscular mycorrhizal fungi. *J. Appl. Microbiol.* 103, 683–690. doi: 10.1111/j.1365-2672.2007.03296.x

Park, H.-J., Floss, D. S., Levesque-Tremblay, V., Bravo, A., and Harrison, M. J. (2015). Hyphal branching during arbuscule development requires Reduced Arbuscular Mycorrhiza1. *Plant Physiol.* 169, 2774–2788.

Pimprikar, P., Carbonnel, S., Paries, M., Katzer, K., Klingl, V., Bohmer, M. J., et al. (2016). A CCaMK-CYCLOPS-DELLA complex activates transcription of RAM1 to regulate arbuscule branching. *Curr. Biol.* 26, 987–998. doi: 10.1016/j.cub.2016.01.069

Ponce-Toledo, R. I., Deschamps, P., Lopez-Garcia, P., Zivanovic, Y., Benzerara, K., and Moreira, D. (2017). An early-branching freshwater cyanobacterium at the origin of plastids. *Curr. Biol.* 27, 386–391. doi: 10.1016/j.cub.2016.11.056

Pozo, M. J., and Azcon-Aguilar, C. (2007). Unraveling mycorrhiza-induced resistance. *Curr. Opin. Plant Biol.* 10, 393–398. doi: 10.1016/j.pbi.2007.05.004

Querejeta, J. I. (2017) "Soil water retention and availability as influenced by mycorrhizal symbiosis: consequences for individual plants, communities, and ecosystems," in *Mycorrhizal Mediation of Soil - Fertility, Structure, and Carbon Storage*, eds N. Collins-Johnson, C. Gehring, and J. Jansa (Amsterdam: Elsevier), 299–317. doi: 10.1016/B978-0-12-804312-7.00017-6

Rapparini, F., and Penuelas, J. (2014). "Mycorrhizal fungi to alleviate drought stress on plant growth," in *Use of Microbes for the Alleviation of Soil Stresses*, ed. M. Miransari (New York, NY: Springer).

Rausch, C., Daram, P., Brunner, S., Jansa, J., Laloi, M., Leggewie, G., et al. (2001). A phosphate transporter expressed in arbuscule-containing cells in potato. *Nature* 414, 462–466. doi: 10.1038/35106601

Read, D. J. (2002) "An ecological point of view on arbuscular mycorrhiza research," in *Mycorrhizal Technology in Agriculture*, eds S. Gianinazzi, H. Schüepp, J. M. Barea, K. Haselwandter (Basel: Birkhäuser), 129–136. doi: 10.1007/978-3-0348-8117-3_11

Read, D. J., Duckett, J. G., Francis, R., Ligrone, R., and Russell, A. (2000). Symbiotic fungal associations in 'lower' land plants. *Philos. Trans. R. Soc. Lond. Ser. B-Biol. Sci.* 355, 815–830. doi: 10.1098/rstb.2000.0617

Redecker, D., Kodner, R., and Graham, L. E. (2000). Glomalean fungi from the Ordovician. *Science* 289, 1920–1921. doi: 10.1126/science.289.5486.1920

Rich, M. K., Courty, P.-E., Roux, C., and Reinhardt, D. (2017a). Role of the GRAS transcription factor ATA/RAM1 in the transcriptional reprogramming of arbuscular mycorrhiza in Petunia hybrida. *BMC Genomics* 18:589. doi: 10.1186/s12864-017-3988-8

Rich, M. K., Nouri, E., Courty, P. E., and Reinhardt, D. (2017b). Diet of arbuscular mycorrhizal fungi – Bread & Butter? *Trends Plant Sci.* 22, 652–660. doi: 10.1016/j.tplants.2017.05.008

Rich, M. K., Schorderet, M., Bapaume, L., Falquet, L., Morel, P., Vandenbussche, M., et al. (2015). A petunia GRAS transcription factor controls symbiotic gene expression and fungal morphogenesis in arbuscular mycorrhiza. *Plant Physiol.* 168, 788–797. doi: 10.1104/pp.15.00310

Rillig, M. C. (2004). Arbuscular mycorrhizae, glomalin, and soil aggregation. *Can. J. Soil Sci.* 84, 355–363. doi: 10.4141/S04-003

Rillig, M. C., Wright, S. F., Nichols, K. A., Schmidt, W. F., and Torn, M. S. (2001). Large contribution of arbuscular mycorrhizal fungi to soil carbon pools in tropical forest soils. *Plant Soil* 233, 167–177. doi: 10.1023/A:1010364221169

Rosendahl, S. (2008). Communities, populations and individuals of arbuscular mycorrhizal fungi. *New Phytol.* 178, 253–266. doi: 10.1111/j.1469-8137.2008.02378.x

Rosendahl, S., McGee, P., and Morton, J. B. (2009). Lack of global population genetic differentiation in the arbuscular mycorrhizal fungus *Glomus mosseae* suggests a recent range expansion which may have coincided with the spread of agriculture. *Mol. Ecol.* 18, 4316–4329. doi: 10.1111/j.1365-294X.2009.04359.x

Roth, R., and Paszkowski, U. (2017). Plant carbon nourishment of arbuscular mycorrhizal fungi. *Curr. Opin. Plant Biol.* 39, 50–56. doi: 10.1016/j.pbi.2017.05.008

Rouphael, Y., Franken, P., Schneider, C., Schwarz, D., Giovannetti, M., Agnolucci, M., et al. (2015). Arbuscular mycorrhizal fungi act as biostimulants in horticultural crops. *Sci. Hortic.* 196, 91–108. doi: 10.1016/j.scienta.2015.09.002

Ruiz-Sanchez, M., Armada, E., Munoz, Y., de Salamone, I. E. G., Aroca, R., Ruiz-Lozano, J. M., et al. (2011). Azospirillum and arbuscular mycorrhizal colonization enhance rice growth and physiological traits under well-watered and drought conditions. *J. Plant Physiol.* 168, 1031–1037. doi: 10.1016/j.jplph.2010.12.019

Sanders, I. R., and Croll, D. (2010). Arbuscular mycorrhiza: the challenge to understand the genetics of the fungal partner. *Annu. Rev. Genet.* 44, 271–292. doi: 10.1146/annurev-genet-102108-134239

Savary, R., Masclaux, F. G., Wyss, T., Droh, G., Corella, J. C., Machado, A. P., et al. (2018). A population genomics approach shows widespread geographical distribution of cryptic genomic forms of the symbiotic fungus *Rhizophagus irregularis*. *ISME J.* 12, 17–30. doi: 10.1038/ismej.2017.153

Schubert, A., and Lubraco, G. (2000). Mycorrhizal inoculation enhances growth and nutrient uptake of micropropagated apple rootstocks during weaning in commercial substrates of high nutrient availability. *Appl. Soil Ecol.* 15, 113–118. doi: 10.1016/S0929-1393(00)00086-X

Schüssler, A., Schwarzott, D., and Walker, C. (2001). A new fungal phylum, the *Glomeromycota*: phylogeny and evolution. *Mycol. Res.* 105, 1413–1421. doi: 10.1017/S0953756201005196

Sedzielewska Toro, K., and Brachmann, A. (2016). The effector candidate repertoire of the arbuscular mycorrhizal fungus Rhizophagus clarus. *BMC Genomics* 17:101. doi: 10.1186/s12864-016-2422-y

Sellal, Z., Ouazzani Touhami, A., Mouden, N., El Ouarraqi, M., Selmaoui, K., Dahmani, J., et al. (2017). Effect of an endomycorrhizal inoculum on the growth of Argan tree. *Int. J. Environ. Agric. Biotechnol.* 2, 928–939. doi: 10.22161/ijeab/2.2.47

Selosse, M. A., Charpin, M., and Not, F. (2017). Mixotrophy everywhere on land and in water: the grand ecart hypothesis. *Ecol. Lett.* 20, 246–263. doi: 10.1111/ele.12714

Sheoran, V., Sheoran, A. S., and Poonia, P. (2010). Soil reclamation of abandoned mine land by revegetation: a review. *Int. J. Soil Sediment Water* 3:13.

Singh, P. K., Singh, M., and Tripathi, B. N. (2013). Glomalin: an arbuscular mycorrhizal fungal soil protein. *Protoplasma* 250, 663–669. doi: 10.1007/s00709-012-0453-z

Smith, S. E., and Read, D. J. (2008). *Mycorrhizal Symbiosis.* 3rd Edn. New York, NY: Academic Press.

Solaiman, Z. M., Abbott, L. K., and Varma, A. (2014). *Mycorrhizal Fungi: Use in Sustainable Agriculture and Land Restauration.* Berlin: Springer.

Solis-Dominguez, F. A., Valentin-Vargas, A., Chorover, J., and Maier, R. M. (2011). Effect of arbuscular mycorrhizal fungi on plant biomass and the rhizosphere microbial community structure of mesquite grown in acidic lead/zinc mine tailings. *Sci. Total Environ.* 409, 1009–1016. doi: 10.1016/j.scitotenv.2010.11.020

Spatafora, J. W., Chang, Y., Benny, G. L., Lazarus, K., Smith, M. E., Berbee, M. L., et al. (2016). A phylum-level phylogenetic classification of zygomycete fungi based on genome-scale data. *Mycologia* 108, 1028–1046. doi: 10.3852/16-042

Tang, N., San Clemente, H., Roy, S., Bécard, G., Zhao, B., and Roux, C. (2016). A survey of the gene repertoire of Gigaspora rosea unravels conserved features among Glomeromycota for obligate biotrophy. *Front. Microbiol.* 7:233. doi: 10.3389/fmicb.2016.00233

Tromas, A., Parizot, B., Diagne, N., Champion, A., Hocher, V., Cissoko, M., et al. (2012). Heart of endosymbioses: transcriptomics reveals a conserved genetic program among arbuscular mycorrhizal, actinorhizal and legume-rhizobial symbioses. *PLoS One* 7:e44742. doi: 10.1371/journal.pone.0044742

Turnau, K., Orlowska, E., Ryszka, P., Zubek, S., Anielska, T., Gawronski, S., et al. (2006). "Role of AMF in phytoremediation and toxicity monitoring of heavy metal rich industrial wastes in Southern Poland," in *Soil and Water Pollution Monitoring, Protection and Remediation*, eds I. Twardowska, H. E. Allen, M. M. Häggblom, and S. Stefaniak (Berlin: Springer).

van der Heijden, M. G. A., and Horton, T. R. (2009). Socialism in soil? The importance of mycorrhizal fungal networks for facilitation in natural ecosystems. *J. Ecol.* 97, 1139–1150. doi: 10.1111/j.1365-2745.2009.01570.x

van der Heijden, M. G. A., Klironomos, J. N., Ursic, M., Moutoglis, P., Streitwolf-Engel, R., Boller, T., et al. (1998). Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. *Nature* 396, 69–72. doi: 10.1038/23932

van der Heijden, M. G. A., Martin, F. M., Selosse, M. A., and Sanders, I. R. (2015). Mycorrhizal ecology and evolution: the past, the present, and the future. *New Phytol.* 205, 1406–1423. doi: 10.1111/nph.13288

Varga, S., Finozzi, C., Vestberg, M., and Kytoviita, M. M. (2015). Arctic arbuscular mycorrhizal spore community and viability after storage in cold conditions. *Mycorrhiza* 25, 335–343. doi: 10.1007/s00572-014-0613-4

Vestberg, M., Cassells, A. C., Schubert, A., Cordier, C., and Gianinazzi, S. (2002) "Arbuscular mycorrhizal fungi and micropropagation of high value crops," in *Mycorrhizal Technology in Agriculture: From Genes to Bioproducts*, eds S. Gianinazzi, H. Schüepp, J. M. Barea, and K. Haselwandter (Basel: Birkhäuser Verlag), 223–234. doi: 10.1007/978-3-0348-8117-3_18

Vigneron, N., Radhakrishnan, G. V., and Delaux, P. M. (2018). What did we learn studying the evolution of the arbuscular mycorrhizal symbiosis? *Curr. Opin. Plant Biol.* 44, 49–56. doi: 10.1016/j.pbi.2018.02.004

Vosatka, M., Albrechtova, J., and Patten, R. (2008). "The international market development for mycorrhizal technology," in *Mycorrhiza*, ed. A. Varma (Berlin: Springer).

Wan, J., Zhang, X. C., and Stacey, G. (2008). Chitin signaling and plant disease resistance. *Plant Signal. Behav.* 3, 831–833. doi: 10.4161/psb.3.10.5916

Wang, B., and Qiu, Y. L. (2006). Phylogenetic distribution and evolution of mycorrhizas in land plants. *Mycorrhiza* 16, 299–363. doi: 10.1007/s00572-005-0033-6

Wang, E. T., Yu, N., Bano, S. A., Liu, C. W., Miller, A. J., Cousins, D., et al. (2014). A H+-ATPase that energizes nutrient uptake during mycorrhizal symbioses in rice and Medicago truncatula. *Plant Cell* 26, 1818–1830. doi: 10.1105/tpc.113.120527

Wang, W. X., Shi, J. C., Xie, Q. J., Jiang, Y. N., Yu, N., and Wang, E. T. (2017). Nutrient exchange and regulation in arbuscular mycorrhizal symbiosis. *Mol. Plant* 10, 1147–1158. doi: 10.1016/j.molp.2017.07.012

Weber, O. B. (2014). "Biofertilizers with arbuscular mycorrhizal fungi in agriculture," in *Mycorrhizal Fungi: Use in Sustainable Agriculture and Restoration, Vol Soil biology*, Vol 41, eds Z. M. Solaiman, L. K. Abbott, and A. Varma (Berlin: Springer).

Weissenhorn, I., Leyval, C., Belgy, G., and Berthelin, J. (1995). Arbuscular mycorrhizal contribution to heavy-metal uptake by maize (*Zea mays* L) in pot culture with contaminated soil. *Mycorrhiza* 5, 245–251.

Wewer, V., Brands, M., and Dörmann, P. (2014). Fatty acid synthesis and lipid metabolism in the obligate biotrophic fungus *Rhizophagus irregularis* during mycorrhization of *Lotus japonicus*. *Plant J.* 79, 398–412. doi: 10.1111/tpj.12566

Wilson, G. W. T., Rice, C. W., Rillig, M. C., Springer, A., and Hartnett, D. C. (2009). Soil aggregation and carbon sequestration are tightly correlated with the abundance of arbuscular mycorrhizal fungi: results from long-term field experiments. *Ecol. Lett.* 12, 452–461. doi: 10.1111/j.1461-0248.2009.01303.x

Wu, Q. S. (2017). *Arbuscular Mycorrhizas and Stress Tolerance of Plants.* Singapore: Springer. doi: 10.1007/978-981-10-4115-0

Yang, S. Y., Gronlund, M., Jakobsen, I., Grotemeyer, M. S., Rentsch, D., Miyao, A., et al. (2012). Nonredundant regulation of rice arbuscular mycorrhizal symbiosis by two members of the PHOSPHATE TRANSPORTER1 gene family. *Plant Cell* 24, 4236–4251. doi: 10.1105/tpc.112.104901

Zhang, Q., Blaylock, L. A., and Harrison, M. J. (2010). Two Medicago truncatula half-ABC transporters are essential for arbuscule development in arbuscular mycorrhizal symbiosis. *Plant Cell* 22, 1483–1497. doi: 10.1105/tpc.110.074955

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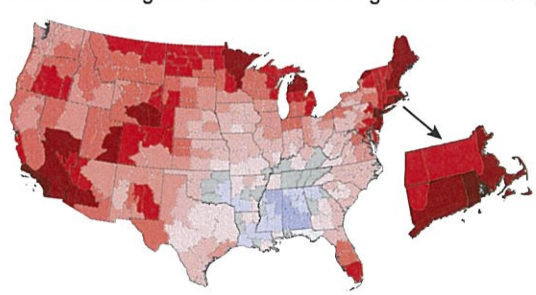
What Climate Change *Means for* Connecticut

Connecticut's climate is changing. The state has warmed two to three degrees (F) in the last century. Throughout the northeastern United States, spring is arriving earlier and bringing more precipitation, heavy rainstorms are more frequent, and summers are hotter and drier. Sea level is rising, and severe storms increasingly cause floods that damage property and infrastructure. In the coming decades, changing the climate is likely to increase flooding, harm ecosystems, disrupt farming, and increase some risks to human health.

Our climate is changing because the earth is warming. Since the late 1700s, people have increased the amount of carbon dioxide in the air by 40 percent. Other heat-trapping greenhouse gases are also increasing. These gases have warmed the surface and lower atmosphere of our planet about one degree during the last 50 years. Evaporation increases as the atmosphere warms, which increases humidity, average rainfall, and the frequency of heavy rainstorms in many places—but contributes to drought in others.

Greenhouse gases are also changing the world's oceans and ice cover. Carbon dioxide reacts with water to form carbonic acid, so the oceans are becoming more acidic. The surface of the ocean has warmed about one degree during the last 80 years. Warming is causing snow to melt earlier in spring, and mountain glaciers are retreating. Even the great ice sheets on Greenland and Antarctica are shrinking. Thus the sea is rising at an increasing rate.



Rising temperatures in the last century. Connecticut has warmed twice as much as the rest of the contiguous 48 states. Source: EPA, Climate Change Indicators in the United States.

Increasing Temperature and Changing Precipitation Patterns

Rising temperatures and shifting rainfall patterns are likely to increase the intensity of both floods and droughts. Average annual precipitation in the Northeast increased 10 percent from 1895 to 2011, and precipitation from extremely heavy storms has increased 70 percent since 1958. During the next century, average annual precipitation and the frequency of heavy downpours are likely to keep rising. Average precipitation is likely to increase during winter and spring, but not change significantly during summer and fall. Rising temperatures will melt snow earlier in spring and increase evaporation, and thereby dry the soil during summer and fall. So flooding is likely to be worse during winter and spring, and droughts worse during summer and fall.

In 2011, Hurricane Irene filled the Connecticut River with muddy sediment as a result of erosion upstream. Heavy storms are becoming more common as a result of climate change. Credit: NASA.

Sea Level Rise, Wetland Loss, and Coastal Flooding

Rising sea level erodes wetlands and beaches and increases damage from coastal storms. Tidal wetlands are inherently vulnerable because of their low elevations, and shoreline development prevents them from migrating inland onto higher ground. Human activities such as filling wetlands have destroyed about one third of New England's coastal wetlands since the early 1800s. Wetlands provide habitat for many bird species, such as osprey and heron, as well as several fish species. Losing coastal wetlands would harm coastal ecosystems and remove an important line of defense against coastal flooding.

Coastal cities and towns will become more vulnerable to storms in the coming century as sea level rises, shorelines erode, and storm surges become higher. Storms can destroy coastal homes, wash out highways and rail lines, and damage essential communication, energy, and wastewater management infrastructure.

Coastal marshes in Old Saybrook and nearby properties are at risk from sea level rise. © James G. Titus; used by permission.

Ecosystems and Agriculture

Changing the climate threatens ecosystems by disrupting relationships between species. Wildflowers and woody perennials are blooming—and migratory birds are arriving—sooner in spring. Not all species adjust in the same way, however, so the food that one species needs may no longer be available when that species arrives on its migration. Warmer temperatures allow deer populations to increase, leading to a loss of forest underbrush, which makes some animals more vulnerable to predators. Rising temperatures also enable invasive species to move into areas that were previously too cold.

Climate change may also pose challenges for agriculture: Warmer temperatures cause cows to eat less and produce less milk. That could reduce the output of Connecticut's $70-million dairy industry, which provides 13 percent of the state's farm revenue. Some farms may be harmed if more hot days and droughts reduce crop yields, or if more flooding and wetter springs delay their planting dates. Other farms may benefit from a longer growing season and the fertilizing effect of carbon dioxide.

Human Health

Changes in temperature and precipitation could increase the incidence of acute and chronic respiratory conditions such as asthma. Higher temperatures can increase the formation of ground-level ozone (smog), a pollutant that can contribute to respiratory problems. Rising temperatures may also increase the length and severity of the pollen season for plants such as ragweed—which has already been observed in other regions. Certain people are especially vulnerable, including children, the elderly, the sick, and the poor.

The risk of some diseases carried by insects may also increase. The ticks that transmit Lyme disease are active when temperatures are above 45°F, so warmer winters could lengthen the season during which ticks can become infected or people can be exposed to the ticks. Higher temperatures would also make more of New England warm enough for the Asian tiger mosquito, a common carrier of West Nile virus. The number of cases may or may not increase, depending on what people do to control insect populations and avoid insect bites.

The sources of information about climate and the impacts of climate change in this publication are: the national climate assessments by the U.S. Global Change Research Program, synthesis and assessment products by the U.S. Climate Change Science Program, assessment reports by the Intergovernmental Panel on Climate Change, and EPA's *Climate Change Indicators in the United States*. Mention of a particular season, location, species, or any other aspect of an impact does not imply anything about the likelihood or importance of aspects that are not mentioned. For more information about climate change science, impacts, responses, and what you can do, visit EPA's Climate Change website at www.epa.gov/climatechange.

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-Associate Professor, Western Connecticut State University, Department of Biological and Environmental Sciences, 8/09 –8/14.

-Assistant Professor, Western Connecticut State University, Department of Biological and Environmental Sciences, 8/04 – 8/09.

-Curatorial Affiliate in Vertebrate Zoology, Yale University, Peabody Museum of Natural History, 12/04 – Present. (nominated and elected by museum curators).

-Connecticut Science Center Fellow, Connecticut Science Center, Hartford CT, 8/08 – 2012.

-Elected President, Sigma Xi WCSU Chapter, Danbury CT, 5/12 – 5/2018; 5/2020 - current.

-Elected Associate Director, Sigma Xi, Northeast Region, 9/17 – Current

Science Education

-Science Partner, Barnard Environmental Magnet School, New Haven, CT, 04/03-06/19.

-Teacher Education and Mentoring Program (TEAM). Certified Mentor by the Connecticut Department of Education, June 2011.

-National Council for Accreditation of Teacher Education Programs (NCATE/CAEP), National Science Teachers Association (NSTA) Reviewer for Science SPA's, Fall 2007 – 2019.

-Beginning Educator Support Certified. Certified by the Connecticut Department of Education to mentor new science teachers. August, 2005.

-Cyber- Scientist Program Developer. A Professional Development Program for in-service and pre-service science teachers, 2003 - 2010.

TEACHING EXPERIENCE

Western Connecticut State University

- (Bio100) Concepts of Biology lecture and lab (non-majors lab science course).
- (Bio107) Scientific Inquiry in the Field.
- (Bio104) Introductory Biology for Majors and Lab.
- (Bio204) Vertebrate Zoology (lab course for majors)
- (Bio 560) Herpetology (graduate course including lecture, lab, and associated field trips).

- (Bio 480) Undergraduate Group Research Course.

- (Hon198) Debating Sustainable Agriculture. An Institute On Science for Global Policy (ISGP) partnership.

- (ED442) Methods in Teaching Secondary Science Education.

GRADUATE STUDENTS

Western Connecticut State University

-Stacy Evans. (2014, MA), " A comparative morphometric analysis of *Stomatolepas elegans* Costa, 1838 and *S. praegustator* Pilsbry, 1910 (Cirrepedia: Balanomorpha: Coronuloidea)."

-Molly O'Leary. (2014, MA), "A comparison of hard and soft edges and their impact on endangered species."

-Christine Lener. (2010, MA), " Sea Turtle Epibionts as an indicator of foraging grounds of the Loggerhead Sea Turtle (*Caretta caretta*) in Casey Key, Florida."

-Diane Murphy, (2011, MA), " Habitat utilization and seasonal movements of a small population of box turtles (*Terrapene c. carolina*) at the northeastern periphery of their range in Dutchess Co., NY."

Yale University/ University of Crete

-Georgia Mantziou. 2006, Ph.D. "Phylogeography and population genetics of *Mauremys rivulata* (Chelonia: Geoemydidae)." Thesis committee member.

AWARDS AND EXTERNAL SUPPORT

Awards

-Excellence in Teaching Award, The National Society of Leadership and Success (WCSU chapter), 5/2014.

-Norton Mezvinsky Trustees Research Awards (WCSU & System Level Award), 3/10

-Ernest A.Lynton Award for the Scholarship of Engagement for Early Career Faculty, New England Resource Center for Higher Education, Nomination, 4/09.

-I4 Initiative, Connecticut Science Center Fellow, 8/08

Research and Scholarship Support

National Oceanic and Atmospheric Administration (NOAA)

- Finding Our Way: Building a College Ready STEM Pipeline for At-Risk High School Youth Through Watershed Stewardship. #NA19NMF0080088 Award Amount $306,200.00. PI- Pinou, 8/2019 – 10/23.

- Finding Our Way: An Experiential Watershed Learning Program for Middle School Children and their families: #NA16NMF0080003 Award Amount $300,178.00. PI- Pinou, 4/2016

– 12/2019.

Connecticut Department of Transportation (DOT)

- Edge effects of road development on the northern most range of the protected slimy salamander (*Plethodon glutinosus*). Pinou invited by Parsons Environmental Engineering Co. and The Connecticut Science Center to Co-PI, **Award - $25,000.00** over 5 years. 1/2010 - 2015.

National Oceanic and Atmospheric Administration (NOAA)

- Student Opportunity for Learning Grant to establish a summer camp for middle school students in collaboration with Danbury Public Schools: #NA10NES4400005 Award Amount $250,000. PI – Pinou, 5/09 – 3/13.

Connecticut State Department of Education, Bureau of Teaching and Learning

-**Mathematics and Science Partnership Grant (MSP), Award - $250,000** over 3 years. Pinou invited to Co-PI with Danbury Public Schools, 1/2010 – 2011.

Endowment for Applied Water Quality Research

-**Water Research Foundation, Award - $45,557.00.** Improving the water quality in Lake Kenosia, CT. PI-Pinou, 1/2010 - 2011.

State of Connecticut, Department of Higher Education (DHE)

-**Teacher Partnership Quality Grant (TQP), Award - $125,000.00.** WestConn Institute for Science Teacher Research (WISTR). PI-Pinou, 4/06 – 6/07.

Private and Corporate Sponsors

-**Praxair-Linde- $5,000.** To support Graduate Student Research Training Fellowship. PI-Pinou, 01/20

-**Goldring Family Foundation, Award - $10,000.00.** To support Terrapin Tracking program. Coordinator- Pinou, 05/19 -2020.

-**Praxair Corporation- $7,500.00.** To support STEM College Readiness programing in middle school children and their families. PI – Pinou, 11/2018

-**Goldring Family Foundation, Award - $7,500.00.** To support students examining relationship between post-migration patterns and genetic diversity of Olive Ridley turtles in Mexican Pacific as well as investigate the barnacle diversity associated with these turtles. PI-Pinou, 11/12 – 11/14.

-**Goldring Family Foundation, Award - $7,500.00.** To support WCSU Great Hollow Interns. Intern Coordinator- Pinou, 05/15.

-**Center for Technological Literacy, Hofstra University, Award - $5000.00.** Start-up funding to develop STEM Leadership in Public Schools. PI-Pinou, 3/09 – 7/09.

- -**Riverhead Foundation for Marine Research and Conservation, Award - $15,000.00.** Project Migration ARGOS Satellite Transmission Time. PI- Pinou, 7/08 – 7/10.

-**Wooster School, Award - $20,000.00.** Project Migration Satellite Transmitter Sponsorship. PI- Pinou, 7/08 -7/10.

-**Crane Co. Foundation, ($10,360.00).** Project Migration Satellite Transmitter Sponsorship. PI- Pinou, 6/08 – 6/10.

INTERNAL FUNDING AND SUPPORT

Scholarship

WestConn Faculty Development Funds

-Total Award - $3,200.00 over 5 years to improve instruction.

CSU/AAUP University Research Grants

- Total Award - $65,000 over 14 years to study sea turtle behavior and their interspecies relationships.

ATTENDANCE AT INVITED WORKSHOPS

-NOAA B-Wet Northeast Regional Meeting, October, 2019, Portland, ME.

- US Department of Education MSP Regional Conference, February, 2010, San Diego, CA.

- NSF NOYCE Teacher Scholarship Program Proposal Writing Workshop, NSF, January 2009, Atlanta, Georgia.
- NSF MSTP STEM Symposium, Hofstra University, March 5-7, 2009, Singer Island, Florida.
- ATLAST Item Writing Workshop, Horizon Research, May 15-16, 2009, Chapel Hill, North Carolina.

SYMPOSIA WORKSHOPS ORGANIZED

- 2021 Sigma Xi Northeast Region Research Conference, WCSU, Danbury, CT, 17 April.
- 2020 Joint Meetings of Ichthyologists and Herpetologists (JMIH), Norfolk, Virginia. *Exemplary Practices in Herpetological Education;* July 20- 26. (Special Invitation).
- 2020 Northeast Natural History Conference, Stamford, CT. *Herpetology Ecology*; April 18-19. (Special Invitation).
- -2020 Science At Night, Danbury, CT. *What Do We Want From Our Lakes?* September 28th, October 26st, November 30th. https://www.wcsu.edu/biology-msbiodiversity/upcoming-events/event-recordings/
- -2019 Science At Night, Danbury, CT. *What Do We Want From Our Lakes?* September 30th, October 21st, November 25th.
- -2020 Science At Night, Danbury, CT. *What Do We Want From Our Lakes?* September 28th, October 26st, November 30th
- 2017 Annual Symposium on Sea Turtle Biology and Conservation, Las Vegas, NV. *Future Trends in Sea Turtle Epibiont Research*; April 15-20. (http://internationalseaturtlesociety.org/workshops/)

PODCASTS & MEDIA PRESENTATIONS

- Academic Minute - *Teaching the Environment*; October 27, 2020. (https://www.insidehighered.com/audio/2020/10/27/teaching-environment).

INVITED SEMINARS

- Cape Eleuthera Institute - *Why study snakes on Cape Eleuthera, Bahamas*?; December 2019.
- New England B-Wet Regional Meeting. Gulf of Maine Research Institute, Portland, Maine – *Finding Our Way;* October 29-30, 2019.
- -State of the Candlewood Lake Conference. Sherman, CT – April 22, 2018.
- Western Connecticut State University & Candlewood Lake Authority – *Triploid Carp Project*; April 2017.
- Beardsley Zoo Evening Lecture Series, CT – *Sea Turtle Conservation in Costa Rica*; June, 2016
- The New York Turtle and Tortoise Society, NY - *Uncovering Marine Biodiversity Through Sea Turtle Conservation*; October, 2015.
- Western Connecticut State University, Department of Biological and Environmental Sciences Research Seminar, CT – *Turtles and Their Barnacles. What to save first?* April, 2013.
- Framingham State University, MA – *Uncovering Marine Biodiversity Through Sea Turtle Conservation*; February, 2012.
- Central Connecticut State University – *Sea Turtle Conservation and Marine Health*; December, 2008.
- University of Guadalajara (CUCBA) – *Sea Turtle Epibionts*; October, 2007.
- University of Puerto Rico at Mayaguez – *Using Technology to Understand Biodiversity*; March 2007.

- Western Connecticut State University, Sigma-XI Research Seminar – *Snake Evolution and Systematics*; March, 2006.

- Western Connecticut State University, Science at Night Lecture Series – *Conservation of Sea Turtles and the Organisms that Live on Them*; April, 2005.

- Yale – Peabody Museum of Natural History, O. C. Marsh Lecture Series – *Sea Turtle Conservation in Mexico*; March, 2005.

RESEARCH COLLABORATIONS

International

Wetlands Conservation and Island Biodiversity

- Petros Lymberakis, Ph. D., Natural History Museum of Crete-University of Crete, Greece. Topic: Island Biodiversity and Conservation.

- Aris Parmakelis, Ph.D., Department of Ecology and Taxonomy, University of Athens, Greece: Topic: Genomic Evolution of Marine Organisms.

Marine Conservation and Community Stewardship

- Ildefonso Enciso, Research Scientists in Marine Ecosystems, University of Guadalajara, CUCBA.
- Frank Paladino and Nathan Robinson, Leatherback Trust, Playa Grande, Costa Rica. Cape Eleuthera Institute, Eleuthera, Bahamas. Topic: Sea Turtle Conservation in the eastern Pacific Ocean.

National

Herpetology and Conservation

-Eric Lazo-Wasem, Yale University, Peabody Museum of Natural History, Division of Invertebrate Zoology. Topic: Systematics of sea turtle epibionts.

-Gisella Caccone, Ph. D., Yale University, Department of Ecology and Evolutionary Biology & Director of the YIBS Laboratory for Molecular Systematics and Conservation Genetics. Topic: Reptilian phylogenetics, molecular systematics, and conservation.

Resource Management and Stewardship

-Rob DiGiovanni, Director, Atlantic Marine Conservation Society, Hampton Bays, NY. Topic: Sea turtle migration.

- Mark Howarth, Director, Candle Wood Lake Authority, Danbury, CT. Topic: Citizen science and Lake stewardship.

-Ed Faison, Ecologist, Highstead Arboretum, Redding, CT. Topic: A survey of amphibians and reptiles found in Highstead Arboretum.

PUBLICATIONS

(# Student Co-Authors, ## Teacher Co-Authors)

Journal Article Preparation

Articles Under Review

Pinou, T., #Plisko, C. & LaBanca, F. [2020]. Informal Learning improves Science Motivation and Self-efficacy. Journal of STEM Outreach [under review].

Published Journal Articles

Pinou, T., Pitzrick, M., Rahaman A., Young, M.A. 2021. Letter to the Editor. JMBE. 22(1): DOI:https://doi.org/10.1128/jmbe.v22il.2199.

Hoefer S., Robinson N.J., Mills S., **Pinou T.** 2021. What the dead tell us about the living: using roadkill to analyze diet and endoparasite prevalence in two Bahamian snakes. Copeia. Ichthyology & Herpetology 109(3):685-690.

Hoefer S., Robinson N.J., **Pinou T.** 2021. Size matters Size matters: Sexual dimorphism in the pelvic spurs of the Bahamas Boa (*Chilabothrus strigilatus strigilatus*). Herpetology Notes 14:201-203.

Reynolds H., [##]Pires J., [##]Lalier N., [##]Brewster J. & **Pinou T**. 2021. Mud as a phenomenon to model energy flow and chemical processes. Science Scope. March/April: 40-45.

Robinson N., [#]Deguzman K., Bonacci-Sullivan L., DiGiovanni R., **Pinou T**. 2020. Do rehabilitated sea turtles resume typical migratory behaviors? Satellite tracking juvenile loggerhead, green, and kemp's ridley turtles in the northeastern USA. Endangered Species Research 43: 133-143, DOI.org/10.3354/esr01065.

Monette M., [##]Pires J., [##]Lalier N., [##]Brewster J. & **Pinou T**. 2020. Migrating beyond the classroom: Enriching STEM education with family-based, self-directed learning. Science and Children. 2020-Jan-S&C-F-2040.R1. (Accepted)

Robinson N.J., [#]Lazo-Wasem E., Butler B.O., Lazo-Wasem E.A., Zardus J.D., **Pinou, T**. 2019. Spatial distribution of epibionts on olive ridley sea turtles at Playa Ostional, Costa Rica. PLoS ONE 14(9): e0218838. https://doi.org/10.1371/journal.pone.0218838.

Majewska, R., Bosak,S., Frankovich, T.A., Ashworth, M.P., Sullivan, M.J., Robinson, N.J., Lazo-Wasem, E. A., **Pinou, T.**, Nel, R., Van de Vijver, B. 2019. Six new epibiotic *Proschkinia* (Bacillariophyta) species and new insights into the genus phylogeny. The European Journal of Phycology, 54(4): 609-631. DOI: 10.1080/09670262.2019.1628307.

Pinou, T. , Domenech, F. , Lazo-Wasem, E., Majewska, R., Pfaller, J. B., Zardus, Robinson, N. J. 2019. Standardizing Sea Turtle Epibiont Sampling: Outcomes of the Epibiont Workshop at the 37th International Sea Turtle Symposium. Marine Turtle Newsletter 157:22-32.

Pinou, T., Prunier, R., [#]Bresson, M., Padilla, I. E., Perez, JF.J., Trejo, A., DiGiovanni, R. A. and N.J. Robinson. 2018. Repeated sampling adds to the genetic diversity of *Lepidochelys olivacea* (Eschscholtz 1829) olive ridley sea turtle. Journal of Natural History 52: 2899-2917, DOI:10.1080/00222933.2018.1557755.

Majewska, R., Ashworth, M.P., Lazo-Wasem, E, Robinson, N.J., Rojas, L., Van de Vijver, B., and **Pinou, T.** 2018. *Craspedostauros alatus* sp. nov., a new diatom species found on museum sea turtle specimens. Diatom Research, 33(2): 229-240, (DOI:10.1080/0269249X.2018.1491426).

Robinson, N. J., C., Figgener, C. Gatto, Lazo-Wasem, E., Paladino, F., Tomillo, P., Zardus, J. and **Pinou, T.** 2017. Assessing potential limitations when characterising the epibiota of marine megafauna: Effect of gender, sampling location, and inter-annual variation on the epibiont communities of olive ridley sea turtles. Journal of Experimental Marine Biology and Ecology. 497: 71-77.

Robinson, N.J., Lazo-Wasem, E., Paladino, F.V., Zardus, J., **Pinou, T**. 2017. Assortative epibiosis on leatherback, olive ridley, and green sea turtles in the Eastern Tropical Pacific. Journal of the Marine Biological Association of the United Kingdom 97:1233-1240. (doi:10.1017/S0025315416000734).

Robinson, N.J., Majewska, R., Nel, R., Paladino, F.V., Rojas, L., Zardus, J., **Pinou, T**. 2016. Epibiotic diatoms are universally present on all sea turtle species. PLOS ONE (Doi:10.1371/journal.pone.0157011)].

Pinou, T, Lazo-Wasem, E. Dion, K. & Zardus, J. 2013. Six degrees of separation in barnacles? Assessing genetic variability in the sea-turtle epibiont *Stomatolepas elegans* (Costa) among turtles, beaches, and oceans. Journal of Natural History. 47(33-34): 2193-2212, DOI: 1080/00222933.2013.798701

Lazo-Wasem, E., **Pinou, T.,** Pena De Niz, A., [#]Feuerstein, A. (2011). Epibionts associated with nesting marine turtles *Lepidochelys olivacea* and *Chelonia mydas* in Jalisco, Mexico: A review and field guide. Bulletin of the Peabody Museum of Natural History 52(2): 221-240.

Pinou, T., [##]Drucker, M., & [##]Studley, E. (2010). An "HOLA" approach to learning science. In R. E. Yager (Ed.). Science for Resolving Issues/Problem. NSTA Press, Arlington, VA. Pp. 235 - 244.

Pinou, T., and #Pioli, J. (2010). Garter Snake hibernacula in Connecticut. Herpetological Review. 41(3): 372 - 373.

Pinou, T., Pena De Niz, A. #Pacete, K. J., Gall, L., and Lazo-Wasem, E. (2009). The moon's relationship to sea turtle nesting. Herpetological Review. 40(4): 409-410.

Pinou, T. ##Flanigan, H., ##Drucker, M. (2009). First-Grade Record Keepers. Science and Children. 46(5): 31 – 35.

Lazo-Wasem, E., **Pinou**, T., Pena De Niz, A., #Salgado, M., #Schenker, E. (2007). New Records of the marine turtle epibiont *Balaenophilus umigamecolus* (Copepoda: Harpacticoida: Balaenophilidae): New host records and possible implications for marine turtle health. Bulletin of the Peabody Museum of Natural History 48(1): 153-157.

#Lener, C. and **Pinou, T**. (2007). Learning with Loggerheads (*Caretta caretta*). Science and Children. 45(1): 24 – 28.

#Mantziou, G., Antoniou, A., Poulakakis, N., Goulielmos, G., Tsigenopoulos, C.S., **Pinou, T.**, and M. Mylonas. (2005). Isolation and characterization of six microsatellite markers in the fresh water turtle *Mauremys rivulata* (Testudines: Geomydidae). Molecular Ecology Notes. 5(4): 727-729.

Pinou, T. and #E. Diamandi. (2004). An Introduction to the Flora and Fauna of Lake Orestias, Kastoria, Greece. Peabody Museum Publication: 31 pages in three languages.

Pinou, T., S. Vicario, #M. Marscher, A. Caccone. (2004). Relict snakes of North America and their relationships to the Caenophidia using Bayesian methods on mitochondrial sequences. Molecular Phylogenetics and Evolution. 32: 563 - 574.

Dowling, H. G. and **Pinou, T.** (2003). Xenodermatid Snakes in America. Herpetological Review 34(1): 20-23.

Pinou, T. and #A. J. R. Carter (2002). *Elaphe obsoleta* Behavior. Herpetological Review 33(4): 313-314.

Pinou, T. and Margaret A. Riley (2001). Nucleotide Polymorphism in Microcin V plasmids from Natural Isolates of Escherichia coli. Plasmid 46: 1-9.

Riley, M., **Pinou, T.,** Wertz, J., Tan, Y., and Valletta, C. (2001). Characterization of the Klebicin B Plasmid of *Klebsiella pneumoniae*. Plasmid 45: 209-221.

Pinou, T. and Herndon G. Dowling. (2000). *Ptyas* versus *Coluber*: A regrettable tangle of names. Herpetological Review 31(3): 136-138.

Gordon, David M., Margaret A. Riley, and ***T. Pinou**. (1998). Diversity and frequency of colicins in E. coli from house mice. Microbiology 144: 2233-2240.

Pinou, T., Tamar Schlick, Bin Li, and Herndon G. Dowling. (1996). Addition of Darwin's third dimension to phyletic trees. Journal of Theoretical Biology 182: 505-512.

Pinou, T., Carla A. Hass, and Linda R. Maxson. (1995). Geographic variation of serum albumin in the monotypic snake genus *Diadophis* (Colubridae: Xenodontinae): Evidence for cryptic species. J. Herpetol. 29(1): 105-110.

Pinou, T., and Herndon G. Dowling. (1994). The phylogenetic relationships of the Central American snake *Tretanhorinus*: Data from morphology and karyology. Amphibia-Reptilia 15(3): 297-305.

Pinou, T. (1993). Relict Caenophidian snakes of North America. Ph.D. Diss., New York University. 236pp.

Invited Papers & Publications

Pinou, T. (2017). Book Review. *Ecoviews Too, Ecology for all Seasons*. Herpetological Review 48(3): 695 – 696.

Pinou, T. (2009). Author Response. Science and Children. 46(8): 8.

Pinou, T. (2007). Teaching with the New York Times. The New York Times Knowledge Network. www.nytimes.com/college.

INVITED MEETING SYMPOSIA PARTICIPATION

Pinou, T. (2017). Man vs Wild: Lessons on the Earth and Human Impacts. 2017 Connecticut Science Educators Annual Conference, Hamden, CT, USA, 18 November.

Pinou, T. and Lazo-Wasem (2008). Epibionts from *Leidochelys olivacea*, in Jalisco, Mexico. The 28th Annual Symposium on Sea Turtle Biology and Conservation, Loreto, Baja California Sur, Mexico, 18-26 January.

Pinou, T. and Lazo-Wasem (2008). Marine Turtle Epibionts – Field Methods, Procedures, and Data Protocol. The 28th Annual Symposium on Sea Turtle Biology and Conservation, Loreto, Baja California Sur, Mexico, 18-26 January.

Pinou, T. and Lazo-Wasem (2008). Status of the barnacle *Stomatolepas* from Jalisco, Mexico. The 28th Annual Symposium on Sea Turtle Biology and Conservation, Lôreto, Baja California Sur, Mexico, 18-26 January.

ABSTRACTS OF PAPERS PRESENTED AT PROFESSIONAL MEETINGS.

LaBanca, F., and **Pinou, T.** 2021. Impact of situated learning in informal settings on science motivation and content knowledge. Paper presented at the American Educational Research Association Annual Meeting: Science Teaching and Learning SIG, Out-of-School Science Roundtable, Washington, DC.

Pinou T., Robinson N.J., Zardus J.D., Rojas L., Lazo-Wasem E. A. 2020. Micro-dermatoglyphic patterns of sea turtle carapaces do not offer phylogenetic insight nor explain characteristic epibiotic associations. 40th Annual International Symposium On Sea Turtle Biology and Conservation. Cartagena, Columbia. Poster presentation.

#Schrull C., **Pinou T.,** Connally N. 2020. Predicting Diamondback Terrapin Road Crossing Mortality Hotspots in Connecticut. 2020 Northeast Natural History Conference. Stamford, CT, USA. Oral Presentation.

Robinson N. J., #Deguzman K., Bonacci-Sullivan L., DiGiovanni R., **Pinou T.** 2019. Satellite tracking of juvenile green, loggerhead, and Kemp's Ridley turtles from rehabilitation centers in southern New England and Long Island, USA. 2019 Long Island Sound Research Conference. Port Jefferson, NY, USA. Poster session and lightning talk.

Robinson N. J., #Deguzman K., Bonacci-Sullivan L., DiGiovanni R.A., **Pinou T.** 2019. Satellite Tracking of Juvenile Green, Loggerhead, and Kemp's Ridley Turtles from Rehabilitation Centers in Southern New England and Long Island, USA. 39th Annual International Symposium On Sea Turtle Biology and Conservation. Charleston, South Carolina, USA. Poster presentation.

Majewska R., Tessier, S., Scheinberg, L., Robinson, N., Lazo-Wasem, E., Rojas, L., **Pinou, T.,** Zyskowski, K., Van de Vijver, B., Hamilton, P., and Poulin, M. (2018). Zoological museum collections as a valuable source of information for epizoic diatom studies. 31st Congress of the Phycological Society of Southern Africa. Poster Presentation.

Majewska R., Tessier, S., Scheinberg, L., Robinson, N., Lazo-Wasem, E., Rojas, L., **Pinou, T.,** Zyskowski, K., Van de Vijver, B., Hamilton, P., and Poulin, M. (2018). A forgotten treasure: how zoological museum collections can contribute to epizoic diatom research. International Diatom Symposium. Berlin. Oral Presentation.

Majewska R., Robinson N.J., Lazo-Wasem E.A., Nel R., Paladino F.V., Rojas L., Zardus J.D., **Pinou T.** (2017). Diatoms on sea turtles: a summary of recent discoveries. 37th Annual Symposium on Sea Turtle Biology and Conservation. Las Vegas, U.S.A. Oral presentation.

Robinson, N.J., Majewska, R., Nel, R., Paladino, F.V., Rojas, L., Zardus, J., **Pinou, T.** (2016). Epibiotic diatoms are universally present on all sea turtle species. 36th Annual Symposium on Sea Turtle Biology and Conservation. Lima, Peru. Poster presentation.

Connally, N., Wong, E., and **Pinou, T.** 2015. *Teaching Science To Non-Majors: A flipped* *classroom experiment.* Conference on "Teaching Large Classes," The Center for Instructional Development and Educational Research (CIDER), Virginia Tech, VI, July, 2015.

Pinou, T., DiGiovanni, R., Enciso-Padilla, I., Jacobo-Perez, F., Barrera, C., Trejo- Robles, A. (2013). Postnesting Behavior of Lepidochelys olivacea from Campamento La Gloria, Jalisco, Mexico. The 33rd Annual Symposium on Sea Turtle Biology and Conservation, Baltimore, MD, 4 - 10 February.

Pinou, T. and #Christine Lener. (2010). Sea Turtle Epibionts an Indicators of Migration Patterns. 2010 Joint Meeting of Ichthyologista and Herpetologists, Providence, RI, 7-12 July 2010. Pp. 41.

Pinou, T., #Pioli, J., Lymberakis, P. (2009). Population structure of *Mauremys rivulata* in natural and artificial wetlands. 11th International Congress on the Zoogeography, Ecology, and Evolution of Eastern Mediterranean, Heraklion, Crete, Greece, 21-25 September 2009. Pp. 171

Pinou, T., Pacete, K. J., Pena De Niz, A. Gall, L., Lazo-Waseum, E. (2007). Lunar Illumination and its impact on sea turtle nesting. The 27th Annual Symposium on Sea Turtle Biology and Conservation, Myrtle Beach, SC, USA, 22-28 February.

Pinou, T., Georgia Mantziou, and Petros Lymberakis. (2005). Understanding the population structure of the turtle *Mauremys rivulata* (Testudines: Bataguridae) on the island of Crete. The Annual joint Meeting of the American Society of Ichthyologists and Herpetologists, The Herpetologist' League, and The Society for the Study of Amphibians and Reptiles, Tampa, Florida, USA, 4 - 11 July.

Pinou, T. and Herndon G. Dowling. (1999). Origins of the North American Snake Fauna. The Annual Joint Meeting of The American Society of Ichthyologists and Herpetologists, The Herpetologists' League, and The Society for the Study of Amphibians and Reptiles. Penn State University, State College Pennsylvania, USA, 24-30 June.

Pinou, T., #Tanya Greenberg, and Sean Rice. (1999). An intraspecific investigation of the hemipenial characters in *Heterodon platyrhinos*. The Annual Joint Meeting of The American Society of Ichthyologists and Herpetologists, The Herpetologists' League, and The Society for the Study of Amphibians and Reptiles. Penn State University, State College Pennsylvania, USA, 24-30 June.

Pinou, T., Ying Tan, and Margaret Riley. (1996). Diversifying selection as a recurring theme in bacteriocin evolution. The annual New England Molecular Evolution Meeting. University of New Hampshire, Duram, New Hampshire, October.

Pinou, T., Tamar Schlick, Bin Li, and Herndon G. Dowling. (1994). The addition of Darwin's third Dimension. The annual New England Molecular Evolution Meeting. Harvard University, Cambridge, Massachusetts, December.

Pinou, T. (1992). Relationships of the "Relict" colubrid snakes of North America, using microcomplement fixation (MC'F). Second Annual Joint Meeting of the American Society of Ichthyologists and Herpetologists, and Herpetologists League. University of Illinois, Champaign-Urbana, June.

Pinou, T. (1991). Microdermatoglyphics versus biochemistry in Opheodrys. Annual meeting of the American Society of Ichthyologists and Herpetologists. American Museum of Natural History, New York, 15-20 June.

Pinou, T. (1990). "Relict" colubroid snakes of North America. Fourth International Congress of Systematic and Evolutionary Biology. University of Maryland, College Park, 1-7 July.

TECHNICAL REPORTS.

Kozuchowski, J. and **Pinou, T.** (2011). A Baseline Study of Phosphorus and Nitrogen Loadings in Lake Kenosia; A Quality Assurance Project Plan (qAPP). Lake Kenosia Commission, Danbury, CT

Cronkite, S., Gruner, H., #O'Leary, M., **Pinou, T.,** and Quinn, D. (2011, 2013, 2015). Five – Year Monitoring of Known Slimy Salamander (*Plethodon glutinosus*) Habitats. Project 18-113, U.S. Route 7 Bypass, Brookfield, Connecticut. Connecticut Department of Transportation (CT DOT).

Pinou, T. (2007, 2012). Specialized Professional Association (SPA) Accreditation Report for WCSU Secondary Science Education Biology Program. The National Council for Accreditation of Teacher Education (NCATE), National Science Teachers Association (NSTA – SPA) for Biological Sciences.

Pinou, T., N. J. Robinson. 2015. Informe Finàl al Minae. La Biodiversidad de epibiontes asociada con las tortugas marinas que desovan en Playa Grande y Playa Ventanas, Costa Rica. Resolucion N° ACT-OR-DR-143-14.

Pinou, T., N. J. Robinson. 2016. Informe Final al Minae. La Biodiversidad de epibiontes asociada con las tortugas marinas que desovan en Guanacaste, Costa Rica. Resolucion N° ACT-OR-DR-099-15

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GEOTECHNICAL
ENVIRONMENTAL
ECOLOGICAL
WATER
CONSTRUCTION MANAGEMENT

35 Nutmeg Drive
Suite 325
Trumbull, CT 06611
T: 203.380.8188
F: 203.375.1529
www.gza.com

September 21, 2021
File No. 05.0046756.02

Mr. Michael Conklin
Wilton Inland Wetlands Commission
238 Danbury Road
Wilton, CT 06897

Re: Proposed Stormwater Structures and Environmental Design
141 Danbury Road, Wilton, CT

Dear Mr. Conklin:

GZA GeoEnvironmental, Inc. (GZA) has prepared this letter on behalf of our Client, FDSPIN 141 DR, LLC, to provide our opinion to the Town of Wilton Inland Wetlands Commission (IWC) regarding the potential for the proposed stormwater structures and infiltration systems at 141 Danbury in Wilton, Connecticut ("Site") to affect the known environmental conditions.

Based on the information provided to us by Tighe & Bond regarding the Stormwater Management Plan, we understand that the stormwater system at the Site includes the installation of two infiltration systems, as shown on Drawing C301 and detailed on Drawing C601 of the submittal to the IWC for the proposed project. The infiltration systems will be comprised of chambers laid flat and encased in stone and will facilitate the infiltration of stormwater into the underlying soils. The infiltration systems are proposed to be located on the southern portion of the Site, in an area currently used as a parking lot, and on the northern portion of the property in an area that currently consists of lawn. Based on information provided to the IWC by GZA per our August 10, 2021 letter, no environmental areas of concern (AOCs) have been identified within the areas proposed for the infiltration systems.

We understand the Stormwater Management Plan also includes two areas where porous pavement will be installed to promote infiltration by allowing runoff to drain through the bituminous pavement using the inherent void space within the aggregate. Runoff then drains through several layers of filter media before being retained in a reservoir course of crushed stone at the bottom of the pavement profile. The reservoir course sits on native grade and allows infiltration. The areas of porous pavement are proposed to be located in the southwestern portion of the Site, in an area that is currently used as a parking lot and does not contain AOCs, and in the northwestern portion of the Site, in an area that currently consists of lawn and paved parking. As discussed in greater detail in the information GZA provided to you in our August 10, 2021 letter, one soil sample (labeled TB-1 on the attached figure and located northwest of the existing building and within the area of proposed porous pavement) associated with a former fuel oil underground storage tank (UST) that was removed from the Site 22 years ago in 1999, contained petroleum-related compounds at a concentration slightly above the Connecticut Department of Energy and Environmental Protection's (CTDEEP) Remediation Standard Regulations (RSR) criteria.

We note that the area of sample TB-1 has been open to infiltration for several decades and no evidence of impacts have been identified in groundwater adjacent to this area (represented by samples from monitoring well MW-4). Further, as described in the information previously provided, this area of soil will be remediated during redevelopment. Remediation activities will be completed concurrently with the proposed redevelopment and will occur prior to the installation of the stormwater structures.

Based on our investigations of the Site and our understanding of the Stormwater Management Plan, it is GZA's professional opinion that the installation of the proposed infiltration systems and porous pavement will not negatively impact soil or groundwater quality or otherwise cause contaminants to enter the ground water or river. Rather, the proposed infiltration will ultimately improve groundwater quality on the Site.

If you should have any questions regarding the information included herein, please feel free to contact Adam Henry at 860-858-3166.

Very truly yours,

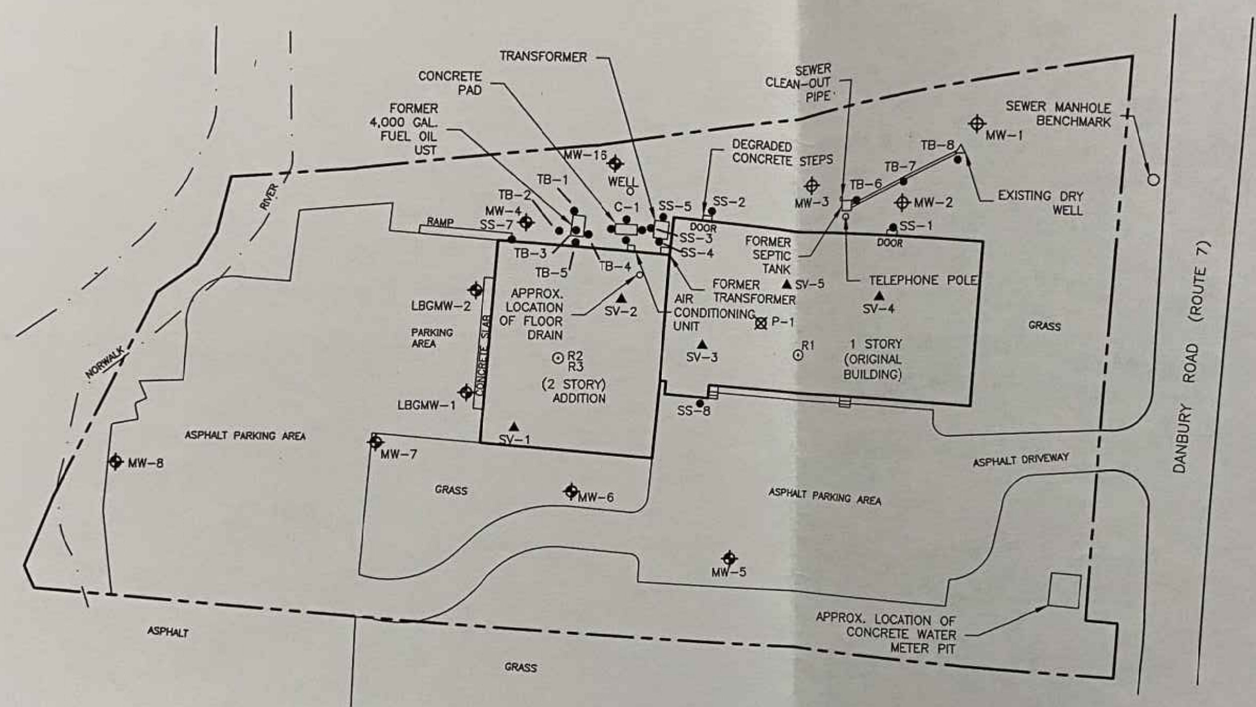
GZA GEOENVIRONMENTAL, INC.

Joseph T. Trzaski, LEP
Senior Project Manager

Adam T. Henry, LEP
Associate Principal

David Rusczyk, PE
Consultant/Reviewer

Attachments: Site Plan and Sampling Locations, 2006, LBG
Porous Pavement Section (T&B)
Drawing C301, Stormwater Management Plan (T&B)



LEGEND

— — —	PROPERTY BOUNDARY
MW-3	MONITOR WELL CONSTRUCTED BY LAND TECH REMEDIAL, INC. IN 1990
MW-5	MONITOR WELL CONSTRUCTED BY GZA IN 1992
LBMW-1	MONITOR WELL CONSTRUCTED BY LGB IN 2006
• SS-8 TB-1	SOIL SAMPLING LOCATIONS BY LBG IN 2006
▲ SV-2	SOIL AND VAPOR SAMPLE COLLECTED BY LBG IN 2006
⊙ R	RADON SAMPLE COLLECTED BY LBG IN 2006
⊠ P-1	POTABLE WATER SAMPLE COLLECTED BY LBG IN 2006

NOTES:

1. MAP BASED ON FIGURE "SITE PLAN, 141 DANBURY ROAD, WILTON, CONNECTICUT FIGURE 2" PREPARED BY GZA, APRIL 28, 2005.
2. THE LOCATION OF THE MONITOR WELLS AND SMAPLE COLLECTION POINTS WERE MEASURED FROM EXISTING SITE FEATURES AND ARE APPROXIMATE.
3. SOIL SAMPLE NOT COLLECTED AT SV-5.
4. DESIGNATION SS-6 NOT USED.

N

0 80
SCALE IN FEET

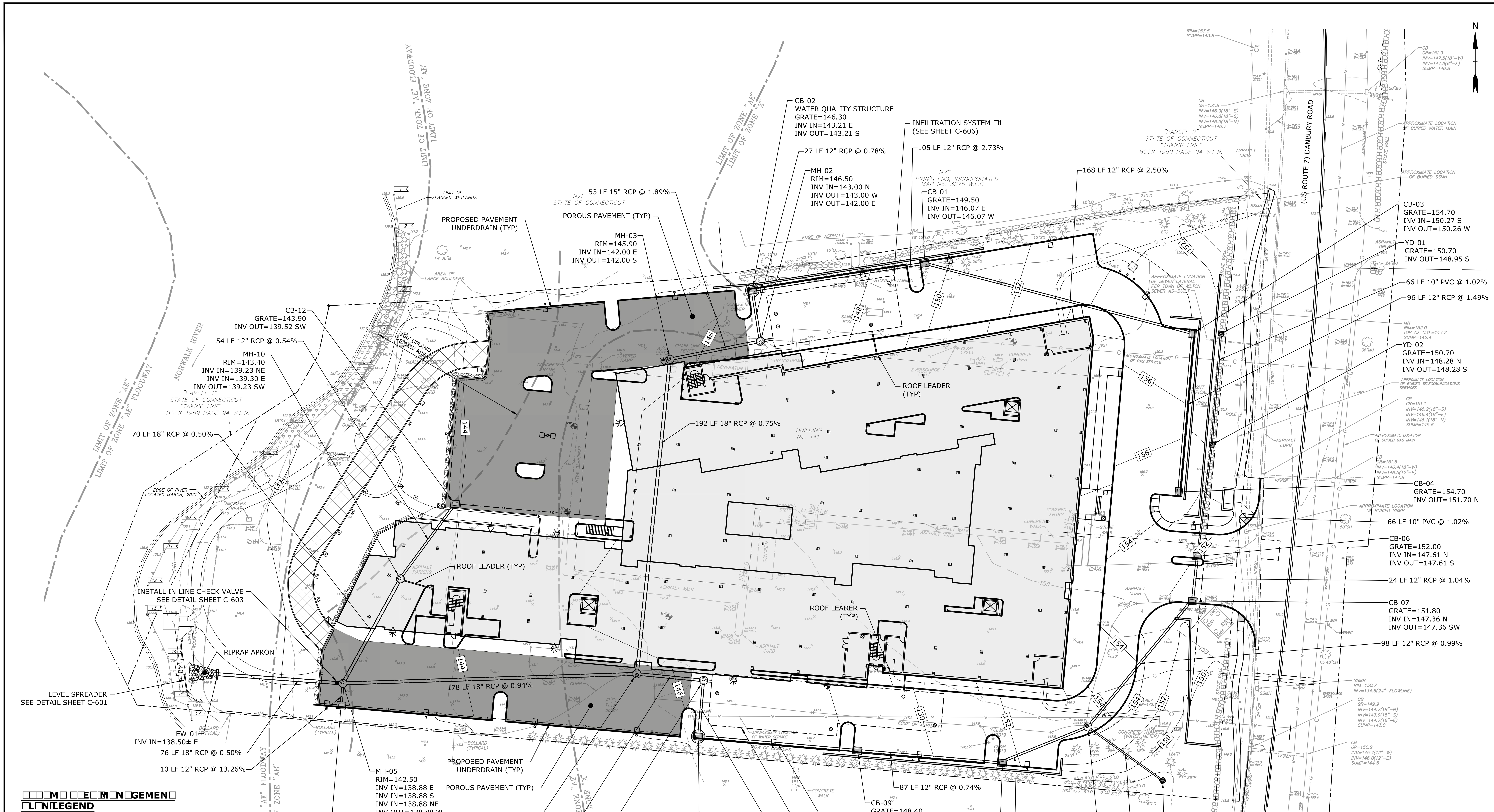
141 DANBURY ROAD
WILTON, CONNECTICUT

SITE PLAN WITH SAMPLING LOCATIONS

DATE	REVISED	PREPARED BY: LEGGETTE, BRASHEARS & GRAHAM, INC. Professional Ground-Water and Environmental Engineering Services 4 Research Drive Suite 301 Shelton, CT 06484 (203) 929-8555

DRAWN: PGR | CHECKED: WB | DATE: 2/2/06 | FIGURE: 2

DWG\LCIINC\Fig-2.dwg, Layout1, 2/3/2006 1:45:54 PM, Canon Graphic Color W2200



STORMWATER MANAGEMENT PLAN LEGEND

- 100 FT UPLAND REVIEW AREA
- PROPERTY LINE
- EASEMENT LINE
- SETBACK LINE
- 25 — EXISTING INDEX CONTOUR
- EXISTING INTERMEDIATE CONTOUR
- X 141.2 — EXISTING SPOT ELEVATION
- 25 — PROPOSED INDEX CONTOUR
- PROPOSED INTERMEDIATE CONTOUR
- + 32.0 — PROPOSED SPOT ELEVATION
- PROPOSED CURB
- PROPOSED RETAINING WALL
- PROPOSED BUILDING
- PROPOSED CATCH BASIN
- PROPOSED YARD DRAIN
- PROPOSED MANHOLE
- PROPOSED POROUS PAVEMENT
- PROPOSED PERMATURF LAWN PANELS

NOTE

1. SURVEY CONDITIONS TAKEN FROM PLAN ENTITLED "TOPOGRAPHIC SURVEY DEPICTING 141 DANBURY ROAD IN WILTON, CONNECTICUT, PREPARED FOR FDSPIN 141 DR LLC" BY D'ANDREA SURVEYING & ENGINEERING, P.C., DATED APRIL 19, 2021, AND IS FOR REFERENCE ONLY.

0 30' 60'
SCALE: 1" = 30'

Tighe&Bond
1000 Bridgeport Avenue
Suite 320
Shelton, CT 06484
(203) 712-1100

ENVIRONMENTAL LAND SOLUTIONS, LLC
Landscape Architecture and Environmental Planning
8 KNIGHT STREET, SUITE 203
NORWALK, CONNECTICUT 06851
Tel: (203) 855-7879 Fax: (203) 855-7836
info@elsllc.net www.elsllc.net

FDSPIN
141 DR, LLC

Wilton, Connecticut

MARK	DATE	DESCRIPTION
1	7/15/2021	REV'D BLDG & SITE LAYOUT

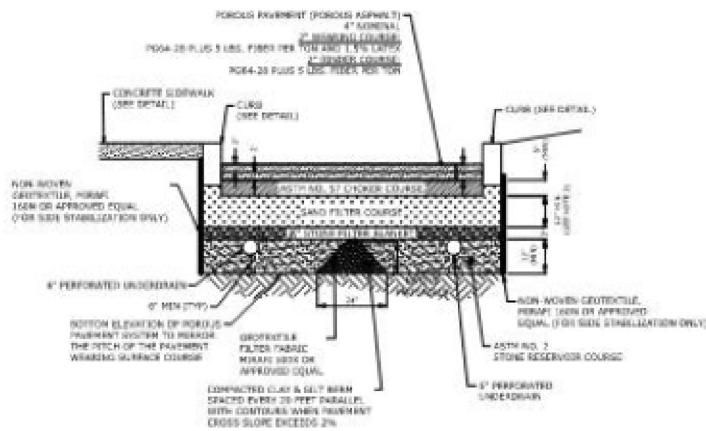
PROJECT NO:	F0173-002
DATE:	06/07/2021
FILE:	F0173-02-C-301-STRM.dwg
DRAWN BY:	MDS
CHECKED:	EWL
APPROVED:	JWB

STORMWATER
MANAGEMENT PLAN

SCALE: 1" = 30'

C-301

Last Saved: 7/12/2021
Plotted On:Jul 14, 2021-1:28pm By: SansoneM
Tighe & Bond:J:\F\F0173 Fuller\002 141 Danbury Road\Drawings-Figures\Sheets\F0173-02-C-301-STRM.dwg



NOTES:

1. SEE SITE PLAN FOR PAVEMENT WIDTH AND LOCATION.
2. SEE GRADING, DRAINAGE, UTILITIES AND EROSION CONTROL PLAN FOR PAVEMENT SLOPE AND CROSS-SLOPE.
3. FILTER COURSE TO BE INCREASED AS NECESSARY TO MEET PROPOSED GRADES.

POROUS PAVEMENT SECTION

NO SCALE

CARMODY
TORRANCE | SANDAK | HENNESSEY LLP

Lisa L. Feinberg
Partner
Direct:203-252-2677
Fax:203-325-8608
LFeinberg@carmodylaw.com

707 Summer Street
Stamford, CT 06901

October 8, 2021

VIA E-MAIL & HAND-DELIVERY

Mike Conklin
Inland Wetlands Commission
Town of Wilton
Town Annex
238 Danbury Road
Wilton, CT 06897

Re: Inland Wetlands Commission Application No. 2714(S)
***Address*: 141 Danbury Road, Wilton, Connecticut**
***Applicant*: FDSPIN 141 DR LLC**

Dear Mr. Conklin:

As you know, our firm represents FDSPIN 141 DR LLC (the **"Applicant"**) in the above-referenced application (the **"Application"**). On behalf of the Applicant, enclosed please find 11 copies following materials in furtherance of the Application:

- Full-size Civil Plans prepared by Tighe & Bond revised in response to comments received from the Town Fire Marshall and 3rd Party Review, dated July 15, 2021 entitled:
  - "Site Layout Plan, C-101," revised to October 8, 2021;
  - "Grading Plan, C-201," revised to October 8, 2021;
  - "Stormwater Management Plan, C-301," revised to October 8, 2021;
  - "Utility Plan, C-401," revised to August 24, 2021;
  - "Soil Erosion and Sediment Control Plan Final Phase, C-502," revised to October 8, 2021;
  - "Details – 2, C-602," revised to August 24, 2021;
  - "Details – 5, C-605," revised to October 8, 2021; and
  - "Details – 8, C-608," revised to August 24, 2021;
- A memorandum prepared by Tighe & Bond, dated October 8, 2201, entitled "Inland Wetlands Commission Third Party Review Comments;"
- A memorandum prepared by Tighe & Bond, dated September 21, 2021, entitled "Department of Public Works/Town Engineer Comments;"
- A Site Soils Report prepared by Tighe & Bond, entitled "Site Soils Information,"
- A report prepared by GZA, dated September 21, 2021, entitled "Proposed Stormwater Structures and Environmental Design, 141 Danbury Road, Wilton, CT;"
- A memorandum prepared by Carmody, Torrance Sandak & Hennessey, dated October 18, 2021, entitled "Response to Commission Inquiry dated September 17, 2021;"
- A manual prepared by Contech Engineered Solutions entitled "CDS Guide, Operation, Design, Performance and Maintenance," and
- Letters of Support for the proposed redevelopment of the Property filed with the Planning & Zoning Commission to date.

We look forward to presenting the enclosed materials to the Inland Wetlands Commission at the October 14th public hearing. Thank you for your time and attention regarding this matter.

Sincerely,

Lisa Feinberg

Lisa L. Feinberg

cc: E. Larkin

{S7339056}

FGI WILTON LLC
525 Homestead Ave, Mt. Vernon, NY 10550
718-384-1110
fgirealtycorp@gmail.com

Planning & Zoning Commission of the Town of Wilton
c/o Michael Wrinn, Planning & Zoning Department Director
238 Danbury Road
Wilton, CT 06897
Michael.Wrinn@WILTONCT.ORG

Re: 141 Danbury Road Proposal (REG #21390, CHZ #21389, SP #481)

Members of the Planning and Zoning Commission:

FGI Wilton, LLC, owners of 131 Danbury Road, conditionally support the applications proposing to redevelop 141 Danbury Road for multi-family residential use. We believe that the high-end materials utilized in the proposed building will enhance the Danbury Road streetscape, as will plantings along the Norwalk River.

Should other aspects of the development, which is under your review, not negatively impede on the integrity of our property as an ongoing commercial property -- including but not limited to the delivery of utilities, rain run-off management, river flooding/flow management and the ability of our tenants to enter and egress our property -- we encourage you to please vote yes on this important proposal.

Thank you,

Larry Moskowitz
VP

Greg Caggainello
100 Scarlet Oak Drive
Wilton, CT 06897

Planning & Zoning Commission of the Town of Wilton
c/o Michael Wrinn, Planning & Zoning Department Director
238 Danbury Road
Wilton, CT 06897
Michael.Wrinn@WILTONCT.ORG

Re: Support for 141 Danbury Road Proposal (REG #21390, CHZ #21389, SP #481)

Dear Chairman Tomasetti and Members of the Planning & Zoning Commission:

We have lived in Wilton for 30 years and our children have been through the Wilton school system. We would like to stay as residents of the Town and now that our kids are out of the house we are considering what alternatives we may have for places to live. We are writing in support of the Application for new luxury apartments at 141 Danbury Road. We have seen the plans which are very attractive and contemporary in feel. This is exactly the type of development people like us would like to live in. The plan shows lots of amenities which we could enjoy with a nice setting along the Norwalk River and it is conveniently located in South Wilton with easy access to both the Village and points South. We also understand that this development will be a major taxpayer in Town and will help revive economic activity for other Town businesses. We urge the Commission to approve this application.

Thank you,

Greg Caggainello

DAVIS MARCUS
PARTNERS

September 14, 2021

Planning & Zoning Commission of the Town of Wilton
c/o Michael Wrinn, Planning & Zoning Department Director
238 Danbury Road
Wilton, CT 06897
Michael.Wrinn@WILTONCT.ORG

Re: Support for 141 Danbury Road Proposal (REG #21390, CHZ #21389, SP #481)

Dear Members of the Planning and Zoning Commission:

Wilton 40/60, an affiliate of Davis Marcus Partners, Inc., as owner of 40 Danbury Road, Wilton, supports the applications proposing to redevelop 141 Danbury Road for multi-family residential use. The re-use of obsolete commercial property as multi-family apartments would be a benefit to the companies in Wilton that are actively hiring new people and also will help to retain empty nesters that are selling their homes but wish to stay in town. The high-end materials utilized in the proposed building will enhance the Danbury Road streetscape, as will plantings along the Norwalk River.

Davis Marcus Partners and its affiliates have been actively involved in Wilton over the past 20+ years as owners and managers of approximately 750,000 square feet of office space along Danbury Road, and we are in full support of the proposed project and its developer, Sam Fuller.

Please vote yes on this important proposal.

Thank you,

Davis Marcus Partners, Inc.

David Fiore

Jeffrey Kaplan
8 Greenbriar Lane
Wilton CT 06897

Planning & Zoning Commission of the Town of Wilton
c/o Michael Wrinn, Planning & Zoning Department Director
238 Danbury Road
Wilton, CT 06897
Michael.Wrinn@WILTONCT.ORG

Re: Support for 141 Danbury Road Proposal (REG #21390, CHZ #21389, SP #481)

Dear Chairman Tomasetti and Members of the Planning & Zoning Commission:

I am writing in strong support of the application at 141 Danbury Road. There are several reasons that I believe this particular multifamily project will be highly beneficial to the town.

I have known this development team for over 15 years and I am very familiar with their outstanding track record. They build and manage high quality multifamily apartment projects that conform to the character of the community and provide a wide range of new Class-A apartments.

Wilton is in dire need of new apartment inventory, including an affordable component, and the proposed plan is exactly what our town should approve in order to attract and keep residents. The POCD survey results indicate that our community will support this endeavor and we trust that your commission will follow through with this vital mission.

I kindly request that the commission approve this application and I look forward to seeing this new project get approved, with shovels in the ground, in the near future.

Time is of the essence and your support will guarantee continued success for our town as we strategically grow our tax base and rebuild our main transportation corridor along Danbury Road.

Warm regards,

Jeff Kaplan

RING'S END
Since 1902

Ring's End, Inc.

September 13, 2021

Planning & Zoning Commission of the Town of Wilton
c/o Michael Wrinn, Planning & Zoning Department Director
238 Danbury Road
Wilton, CT 06897

Michael.Wrinn@WILTONCT.ORG

Re: Support for 141 Danbury Road Proposal (REG #21390, CHZ #21389, SP #481)

Dear Chairman Tomasetti and Members of the Planning & Zoning Commission:

On behalf of Ring's End, Inc., owner of the property located at 149 Danbury Road and 129 Danbury Road, I write to you in support of the proposed redevelopment of 141 Danbury Road. The proposed building will be a welcome addition to our neighborhood, and will help the Town meet the growing demand for living opportunities here in Wilton. As next-door neighbors to the subject property, we appreciate the significant investment being made in both the proposed building and the significant landscaping along the Norwalk River. We hope the Commission will take advantage of this tremendous opportunity for the Wilton community and approve this proposal.

Thank you,

Sincerely,

Louis J Reda
CFO – Exec VP

181 West Avenue
Darien, Connecticut 06820
800-390-1000 • RingsEnd.com

September 14, 2021

Planning & Zoning Commission of the Town of Wilton
c/o Michael Wrinn, Planning & Zoning Department Director
238 Danbury Road
Wilton, CT 06897
Michael.Wrinn@WILTONCT.ORG

Re: Support for 141 Danbury Road Proposal (REG #21390, CHZ #21389, SP #481)

Dear Members of the Planning and Zoning Commission:

Wilton – 50 Danbury Road Owner LLC and Wilton – 64 Danbury Road Owner LLC the respective owners of 50 and 64 Danbury Road, Wilton, support the applications proposing to redevelop 141 Danbury Road for multi-family residential use. We believe that the re-use of the property as multi-family apartments would be a benefit to the companies in Wilton that are actively hiring new people and also will help to retain empty nesters that are selling their homes but wish to stay in town. Further, it is our belief that the high-end materials utilized in the proposed building will enhance the Danbury Road streetscape, as will plantings along the Norwalk River.

Each of Wilton – 50 Danbury Road Owner LLC and Wilton – 64 Danbury Road Owner LLC are in full support of the proposed project and its developer, Sam Fuller.

Please vote yes on this important proposal.

Thank you,

Wilton – 50 Danbury Road Owner LLC
Wilton – 64 Danbury Road Owner LLC

By: ______________________
Name: Peyton McNutt
Title: Authorized Signatory

Deborah J Robertson
68 Wilton Crest
Wilton, CT 06897

Planning & Zoning Commission of the Town of Wilton
c/o Michael Wrinn, Planning & Zoning Department Director
238 Danbury Road
Wilton, CT 06897
Michael.Wrinn@WILTONCT.ORG

Re: Support for 141 Danbury Road Proposal (REG #21390, CHZ #21389, SP #481)

Dear Chairman Tomasetti and Members of the Planning & Zoning Commission:

My husband and I live at 68 Wilton Crest on River Road. We love Wilton but had a difficult time finding quality rental housing in town when we sold our large home. It is in the town's best interest to provide more options for "empty nester's" that no longer need a large house once their children are grown. More rental housing will provide options for seniors as well as young couples. Rental residential housing is good for the community and helps support the many retail stores and restaurant's in Wilton. Without good rental options in town residents will move to other neighboring towns (Stamford, Westport, Norwalk) and no longer support the Wilton business community. I write to you now in support of the proposed redevelopment of 141 Danbury Road. The proposed building will be a welcome addition to the Town and will provide much needed state-of-the-art apartment alternative. We hope the Commission will approve these plans and provide this important choice for both present and future Wilton Residents.

Thank you,

Deborah J Robertson

Jeffrey Kaplan
8 Greenbriar Lane
Wilton CT 06897

Planning & Zoning Commission of the Town of Wilton
c/o Michael Wrinn, Planning & Zoning Department Director
238 Danbury Road
Wilton, CT 06897
Michael.Wrinn@WILTONCT.ORG

Re: Support for 141 Danbury Road Proposal (REG #21390, CHZ #21389, SP #481)

Dear Chairman Tomasetti and Members of the Planning & Zoning Commission:

I am writing in strong support of the application at 141 Danbury Road. There are several reasons that I believe this particular multifamily project will be highly beneficial to the town.

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Wilton is in dire need of new apartment inventory, including an affordable component, and the proposed plan is exactly what our town should approve in order to attract and keep residents. The POCD survey results indicate that our community will support this endeavor and we trust that your commission will follow through with this vital mission.

I kindly request that the commission approve this application and I look forward to seeing this new project get approved, with shovels in the ground, in the near future.

Time is of the essence and your support will guarantee continued success for our town as we strategically grow our tax base and rebuild our main transportation corridor along Danbury Road.

Warm regards,

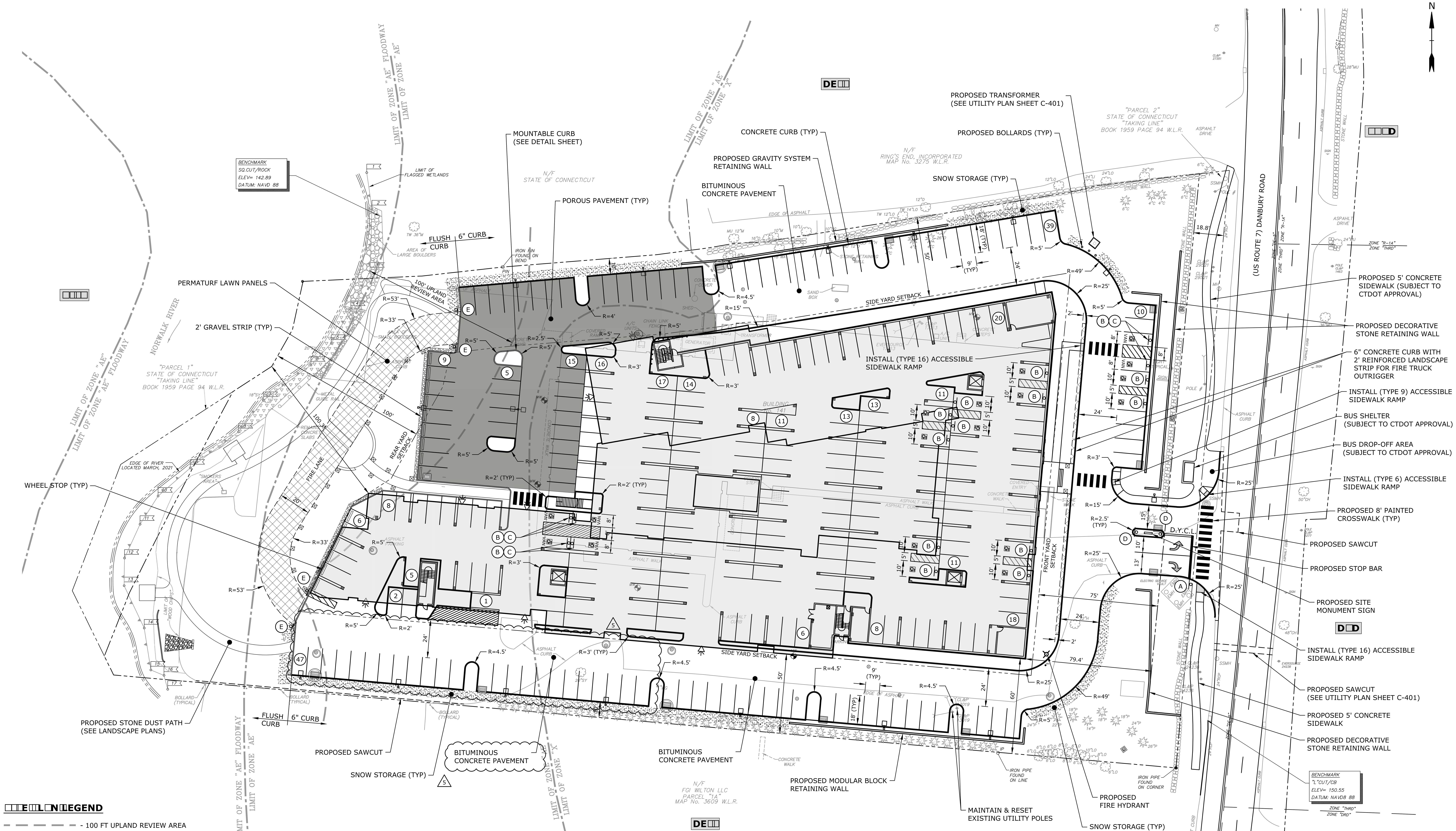
Jeff Kaplan

Tighe&Bond
1000 Bridgeport Avenue
Suite 320
Shelton, CT 06484
(203) 712-1100

ELS
ENVIRONMENTAL LAND SOLUTIONS, LLC
Landscape Architecture and Environmental Planning
8 KNIGHT STREET, SUITE 203
NORWALK, CONNECTICUT 06851
Tel: (203) 855-7879 Fax: (203) 855-7836
info@elsllc.net www.elsllc.net

FDSPIN
141 DR, LLC

Wilton, Connecticut



LEGEND

- 100 FT UPLAND REVIEW AREA
- PROPERTY LINE
- EASEMENT LINE
- SETBACK LINE
- PROPOSED CURB
- PROPOSED RETAINING WALL
- PROPOSED BUILDING
- PROPOSED SIGN
- PROPOSED LIGHT FIXTURE
- PROPOSED CATCH BASIN
- PROPOSED YARD DRAIN
- PROPOSED MANHOLE
- PROPOSED ACCESSIBLE SYMBOL
- PROPOSED POROUS PAVEMENT
- PROPOSED PERMATURF LAWN PANELS
- SNOW STORAGE AREA

PARKING SUMMARY

REGULAR SPACES	- 295
ACCESSIBLE SPACES	- 18
TOTAL SPACES	- 313

SIGN LEGEND

(A) STOP
(B) RESERVED PARKING PERMIT REQUIRED VIOLATORS WILL BE FINED MIN $150
(C) VAN ACCESSIBLE
(D)
(E) EMERGENCY ACCESS ONLY

AREA AND BULK REQUIREMENTS	DE-5	DE-5R	EXISTING	PROPOSED
MIN FRONT YARD	100	75	80.1	79.4
MIN SIDE YARD (EACH)	50	50	49.4	50
MIN. REAR YARD	100	100	167.8	100.3
MIN. PARKING & LOADING SETBACKS (SIDE AND REAR YARDS)	25	10	0	10
MAX. BUILDING HEIGHT (FEET)	39	55*	30	55*
MAX. BUILDING COVERAGE (%)	25%	40%	18.09%	36.32%
MAX. SITE COVERAGE (%)	50%	75%	63.28%	67.80%
MIN. LOT SIZE (ACRES)	5	3	4.28	4.28
MIN. LOT FRONTAGE	150	150	373.41'	373.41'

* - AN ADDITIONAL 10-FEET MAY BE PERMITTED TO ACCOMMODATE AN ADDITIONAL ONE-HALF STORY.

NOTE

1. SURVEY CONDITIONS TAKEN FROM PLAN ENTITLED "TOPOGRAPHIC SURVEY DEPICTING 141 DANBURY ROAD IN WILTON, CONNECTICUT, PREPARED FOR FDSPIN 141 DR LLC" BY D'ANDREA SURVEYING & ENGINEERING, P.C., DATED APRIL 19, 2021, AND IS FOR REFERENCE ONLY.

0 30' 60'
SCALE: 1" = 30'

MARK	DATE	DESCRIPTION
5	10/8/2021	3RD PARTY REVIEW COMMENTS
4	8/24/2021	FIRE MARSHALL COMMENTS
3	8/12/2021	FIRE MARSHALL COMMENTS
2	7/19/2021	REV'D ZONING TABLE
1	7/15/2021	REV'D BLDG & SITE LAYOUT

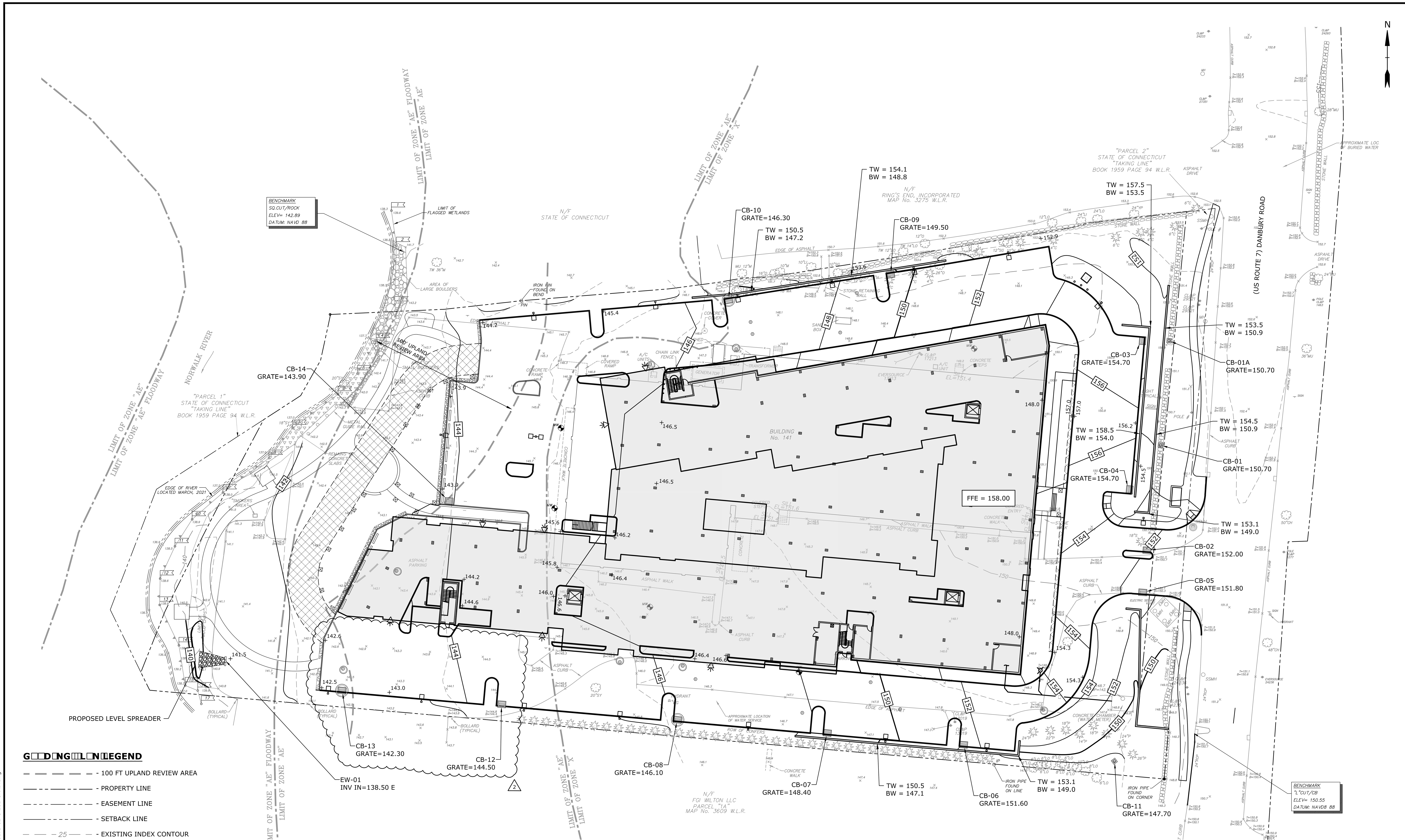
PROJECT NO:	F0173-002
DATE:	06/07/2021
FILE:	F0173-02-C-101-SITE.dwg
DRAWN BY:	TAS
CHECKED:	EWL
APPROVED:	JWB

SITE LAYOUT PLAN

SCALE: 1" = 30'

C-101

Last Saved: 10/8/2021
Plotted On:Oct 08, 2021-9:28am By: TAS
Tighe & Bond: J:\F\F0173 Fuller\002 141 Danbury Road\Drawings-Figures\Sheets\F0173-02-C-101-SITE.dwg



GRADING PLAN LEGEND

- 100 FT UPLAND REVIEW AREA
- PROPERTY LINE
- EASEMENT LINE
- SETBACK LINE
- 25 - EXISTING INDEX CONTOUR
- EXISTING INTERMEDIATE CONTOUR
- X 141.2 - EXISTING SPOT ELEVATION
- 25 - PROPOSED INDEX CONTOUR
- PROPOSED INTERMEDIATE CONTOUR
- + 32.0 - PROPOSED SPOT ELEVATION
- PROPOSED RETAINING WALL
- PROPOSED BUILDING
- PROPOSED POROUS PAVEMENT
- PROPOSED PERMATURF LAWN PANELS
- PROPOSED CATCH BASIN
- PROPOSED YARD DRAIN
- TEST PIT LOCATION
- SOIL BORING LOCATION

GRADING PLAN NOTES

1. THE CONTRACTOR SHALL VERIFY ALL GRADES AND EXISTING CONDITIONS, AND REPORT ANY DISCREPANCIES TO THE OWNER'S REPRESENTATIVE.
2. MAKE SMOOTH TRANSITIONS BETWEEN ALL SLOPE CHANGES AND FEATHER EDGES OF ALL CUTS AND FILLS TO BLEND WITH EXISTING CONDITIONS.
3. PRIOR TO PAVING, PLANTING AND SEEDING, ALL FINAL GRADING SHALL BE APPROVED BY THE OWNER'S REPRESENTATIVE.
4. ADJUST ALL EXISTING AND RELOCATED UTILITY COLLARS, FRAMES, INLETS, VALVE BOXES, ETC. TO MEET NEW GRADES.
5. ADJUST ALL EXISTING AND RELOCATED MANHOLES, CATCH BASINS AND UTILITY STRUCTURES TO TNEW ELEVATIONS WHERE REQUIRED.
6. ALL EXCAVATED MATERIAL NOT REQUIRED FOR GRADING OR FILLING SHALL BE REMOVED PROMPTLY FROM THE SITE AND DISPOSED OF LEGALLY.
7. SURVEY CONDITIONS TAKEN FROM PLAN ENTITLED "TOPOGRAPHIC SURVEY DEPICTING 141 DANBURY ROAD IN WILTON, CONNECTICUT, PREPARED FOR FDSPIN 141 DR LLC" BY D'ANDREA SURVEYING & ENGINEERING, P.C., DATED APRIL 19, 2021, AND IS FOR REFERENCE ONLY.
8. ACCESSIBLE SPACES TO BE GRADED AT 2% OR LESS.
9. ACCESSIBLE ROUTE TO BUILDING NOT TO EXCEED 5%

Tighe&Bond
1000 Bridgeport Avenue
Suite 320
Shelton, CT 06484
(203) 712-1100

ELS
ENVIRONMENTAL LAND SOLUTIONS, LLC
Landscape Architecture and Environmental Planning
8 KNIGHT STREET, SUITE 203
NORWALK, CONNECTICUT 06851
Tel: (203) 855-7879 Fax: (203) 855-7836
info@elsllc.net www.elsllc.net

FDSPIN
141 DR, LLC

Wilton, Connecticut

MARK	DATE	DESCRIPTION
2	10/8/2021	3RD PARTY REVIEW COMMENTS
1	7/15/2021	REV'D BLDG & SITE LAYOUT

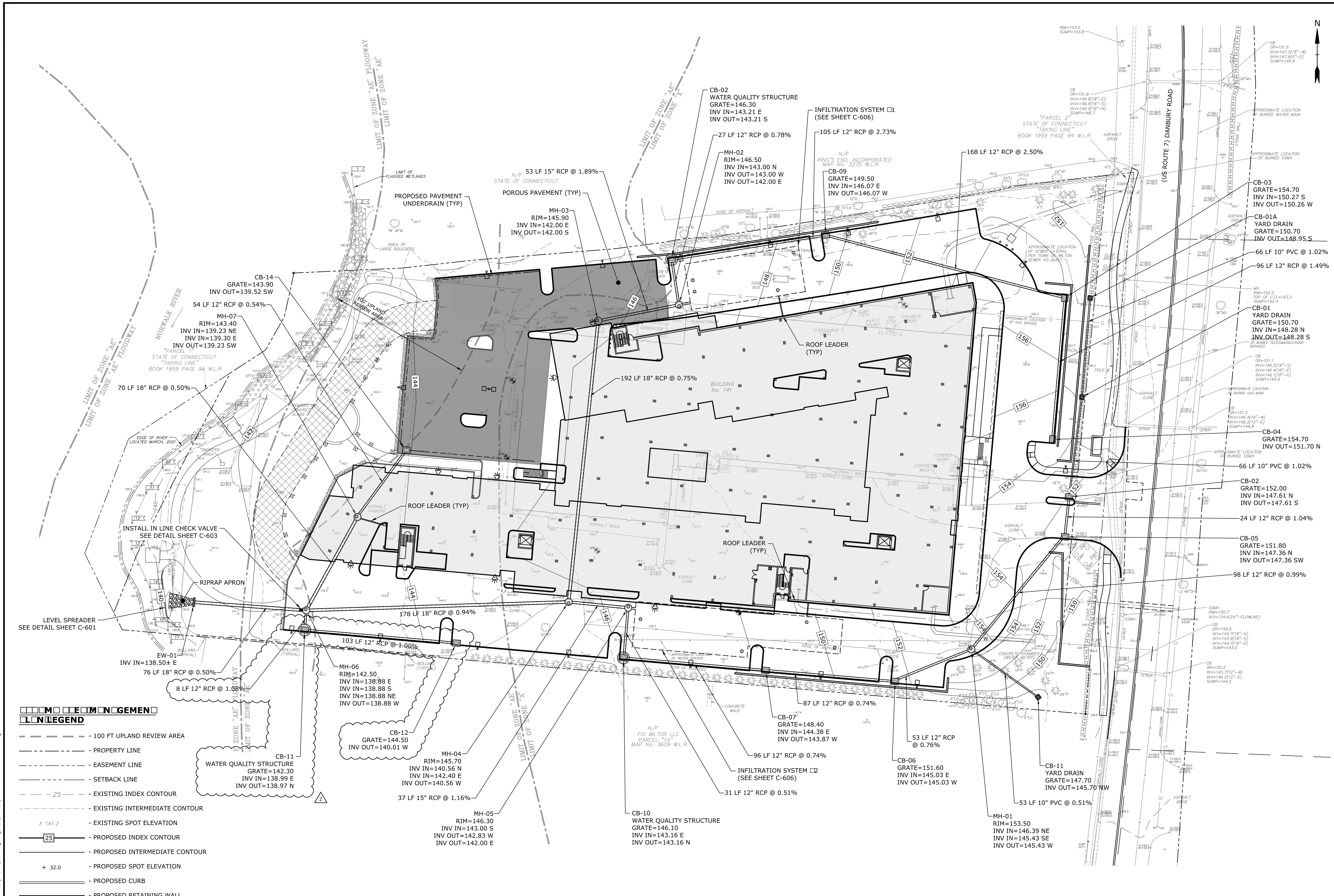
PROJECT NO:	F0173-002
DATE:	06/07/2021
FILE:	F0173-02-C-201-GRAD.dwg
DRAWN BY:	TAS
CHECKED:	EWL
APPROVED:	JWB

GRADING PLAN

SCALE: 1" = 30'

C-201

Last Saved: 10/8/2021
Plotted On:Oct 08, 2021-9:30am By: TAS
Tighe & Bond:J:\F\F0173 Fuller\002 141 Danbury Road\Drawings-Figures\Sheets\F0173-02-C-201-GRAD.dwg



STORMWATER MANAGEMENT PLAN LEGEND

- 100 FT UPLAND REVIEW AREA
- PROPERTY LINE
- EASEMENT LINE
- SETBACK LINE
- 25 EXISTING INDEX CONTOUR
- EXISTING INTERMEDIATE CONTOUR
- X 141.2 EXISTING SPOT ELEVATION
- 25 PROPOSED INDEX CONTOUR
- PROPOSED INTERMEDIATE CONTOUR
- + 32.0 PROPOSED SPOT ELEVATION
- PROPOSED CURB
- PROPOSED RETAINING WALL
- PROPOSED BUILDING
- PROPOSED CATCH BASIN
- PROPOSED YARD DRAIN
- PROPOSED MANHOLE
- PROPOSED POROUS PAVEMENT
- PROPOSED PERMATURF LAWN PANELS

NOTE

1. SURVEY CONDITIONS TAKEN FROM PLAN ENTITLED "TOPOGRAPHIC SURVEY DEPICTING 141 DANBURY ROAD IN WILTON, CONNECTICUT, PREPARED FOR FDSPIN 141 DR LLC" BY D'ANDREA SURVEYING & ENGINEERING, P.C., DATED APRIL 19, 2021, AND IS FOR REFERENCE ONLY.

0 30' 60'
SCALE: 1" = 30'

Tighe&Bond
1000 Bridgeport Avenue
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(203) 712-1100

ELS
ENVIRONMENTAL LAND SOLUTIONS, LLC
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NORWALK, CONNECTICUT 06851
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info@elsllc.net www.elsllc.net

10/8/21

JOHN W. BLOCK
LICENSED PROFESSIONAL ENGINEER
10/8/21

FDSPIN
141 DR, LLC

Wilton, Connecticut

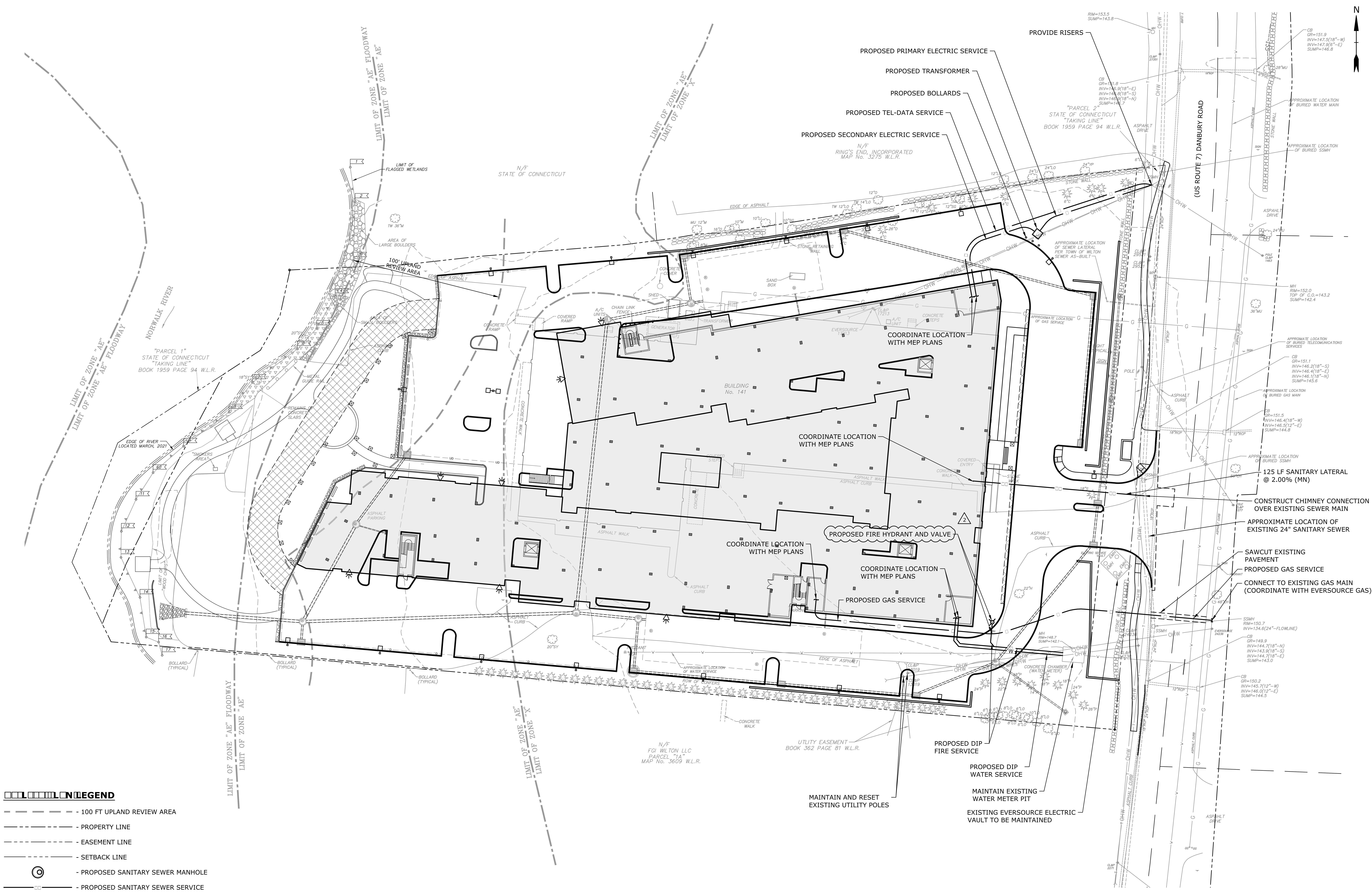
MARK	DATE	DESCRIPTION
2	10/8/2021	3RD PARTY REVIEW COMMENTS
1	7/15/2021	REV'D BLDG & SITE LAYOUT

PROJECT NO:	F0173-002
DATE:	06/07/2021
FILE:	F0173-02-C-301-STRM.dwg
DRAWN BY:	TAS
CHECKED:	EWL
APPROVED:	JWB

STORMWATER MANAGEMENT PLAN

SCALE: 1" = 30'

C-301



LEGEND

- 100 FT UPLAND REVIEW AREA
- PROPERTY LINE
- EASEMENT LINE
- SETBACK LINE
- PROPOSED SANITARY SEWER MANHOLE
- PROPOSED SANITARY SEWER SERVICE
- PROPOSED ELECTRIC SERVICE
- PROPOSED TEL-DATA SERVICE
- PROPOSED WATER SERVICE
- PROPOSED FIRE SERVICE
- PROPOSED GAS SERVICE
- PROPOSED CATCH BASIN
- PROPOSED YARD DRAIN
- PROPOSED MANHOLE

NOTE

1. SURVEY CONDITIONS TAKEN FROM PLAN ENTITLED "TOPOGRAPHIC SURVEY DEPICTING 141 DANBURY ROAD IN WILTON, CONNECTICUT, PREPARED FOR FDSPIN 141 DR LLC" BY D'ANDREA SURVEYING & ENGINEERING, P.C., DATED APRIL 19, 2021, AND IS FOR REFERENCE ONLY.

SCALE: 1" = 30'

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FDSPIN
141 DR, LLC

Wilton, Connecticut

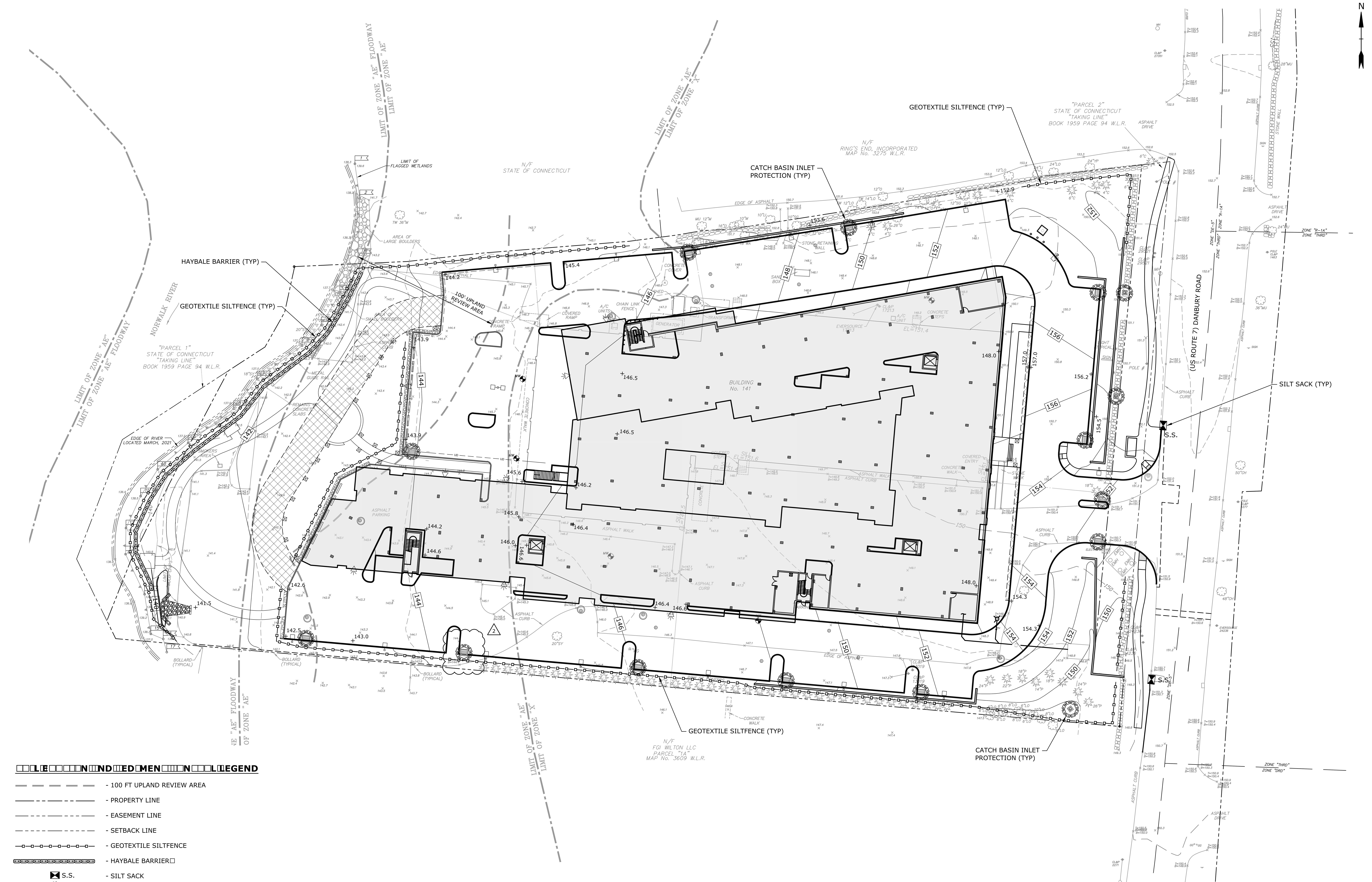
MARK	DATE	DESCRIPTION
2	8/24/2021	FIRE MARSHALL COMMENTS
1	7/15/2021	REV'D BLDG & SITE LAYOUT

PROJECT NO:	F0173-002
DATE:	06/07/2021
FILE:	F0173-02-C-401-UTIL.dwg
DRAWN BY:	MDS
CHECKED:	EWL
APPROVED:	JWB

UTILITY PLAN

SCALE: 1" = 30'

C-401



LEGEND

- 100 FT UPLAND REVIEW AREA
- PROPERTY LINE
- EASEMENT LINE
- SETBACK LINE
- GEOTEXTILE SILTFENCE
- HAYBALE BARRIER
- S.S. - SILT SACK
- CATCH BASIN INLET PROTECTION
- HAYBALE CHECK DAM
- DE-WATERING SUMP
- CONSTRUCTION ENTRANCE
- SOIL STOCKPILE AREA - SOIL STOCKPILE AREA

NOTE

1. SURVEY CONDITIONS TAKEN FROM PLAN ENTITLED "TOPOGRAPHIC SURVEY DEPICTING 141 DANBURY ROAD IN WILTON, CONNECTICUT, PREPARED FOR FDSPIN 141 DR LLC" BY D'ANDREA SURVEYING & ENGINEERING, P.C., DATED APRIL 19, 2021, AND IS FOR REFERENCE ONLY.

0 30' 60'
SCALE: 1" = 30'

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FDSPIN
141 DR, LLC

Wilton, Connecticut

MARK	DATE	DESCRIPTION
2	10/8/2021	3RD PARTY REVIEW COMMENTS
1	7/15/2021	REV'D BLDG & SITE LAYOUT

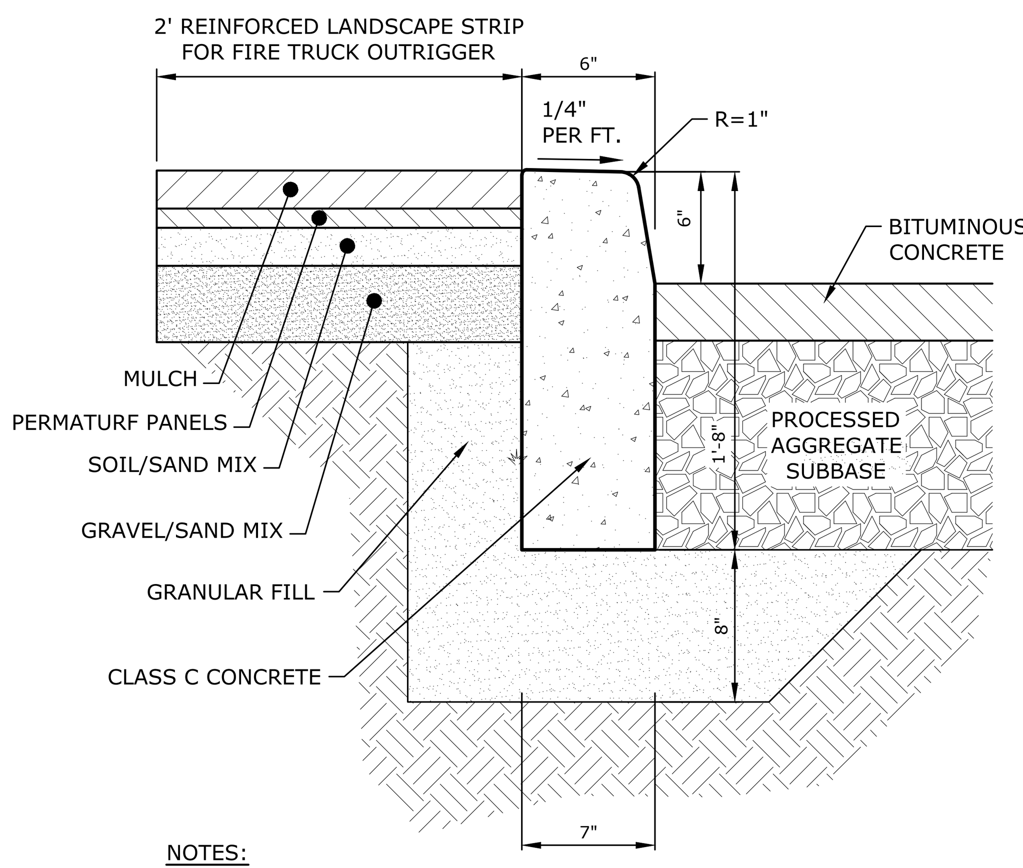
PROJECT NO:	F0173-002
DATE:	06/07/2021
FILE:	F0173-02-C-501-SESC.dwg
DRAWN BY:	TAS
CHECKED:	EWL
APPROVED:	JWB

SOIL EROSION AND SEDIMENT CONTROL PLAN FINAL PHASE

SCALE: 1" = 30'

C-502

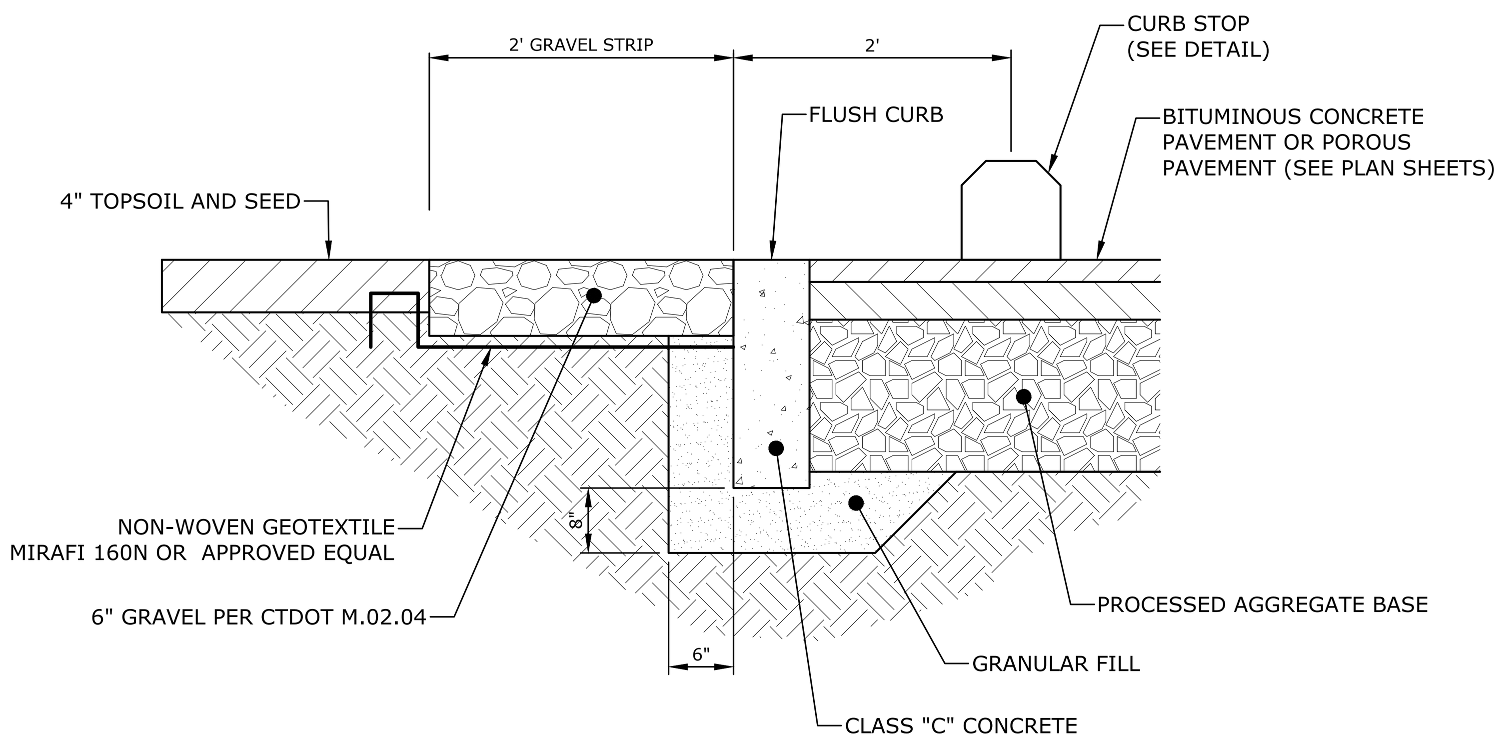
Last Saved: 10/8/2021
Plotted On:Oct 08, 2021-9:33am By: TAS
Tighe & Bond:J:\F\F0173 Fuller\002 141 Danbury Road\Drawings-Figures\Sheets\F0173-02-C-501-SESC.dwg



NOTES:

1. CONSTRUCT CURBING IN SECTIONS NOT TO EXCEED 10 FEET IN LENGTH, SUCH THAT THE CURBING JOINTS ALIGN WITH JOINTS IN THE CONCRETE PAVEMENT SLAB. NO SECTION SHALL BE LESS THAN 6 FEET IN LENGTH.

[illegible]
NO SCALE



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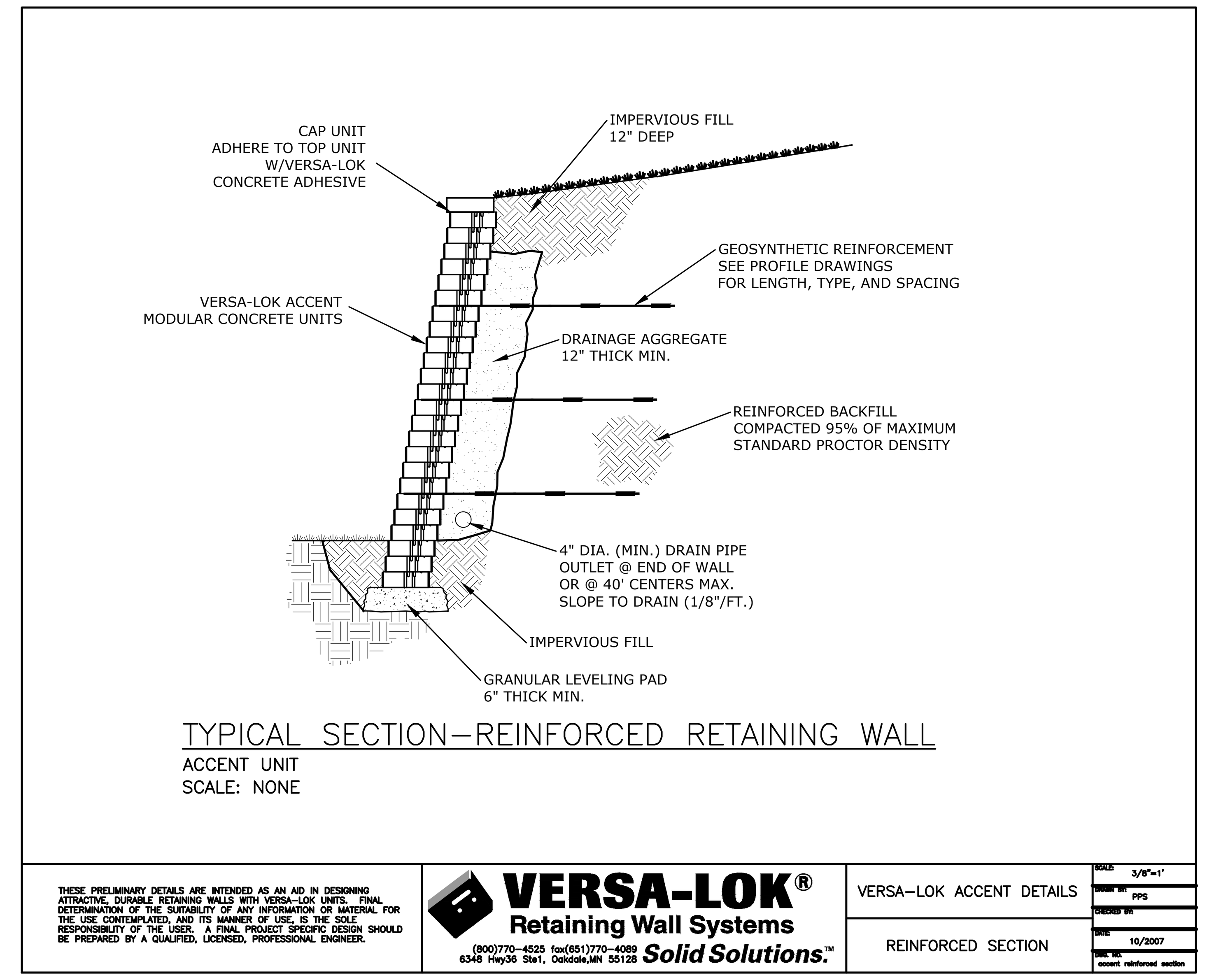
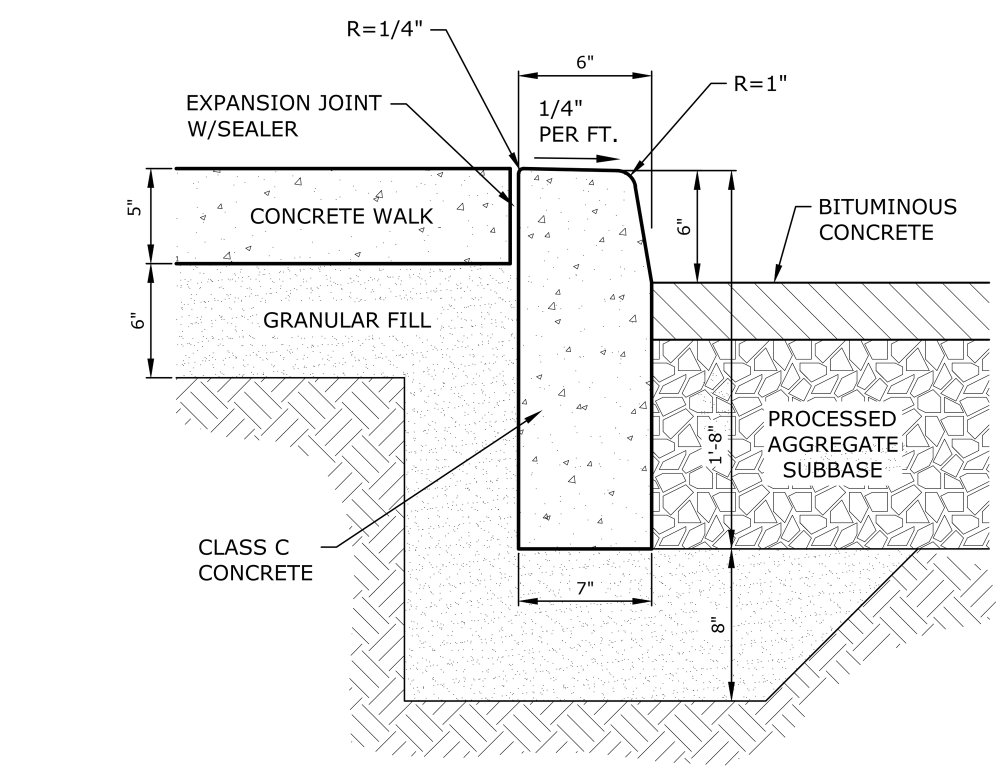


OR APPROVED EQUAL

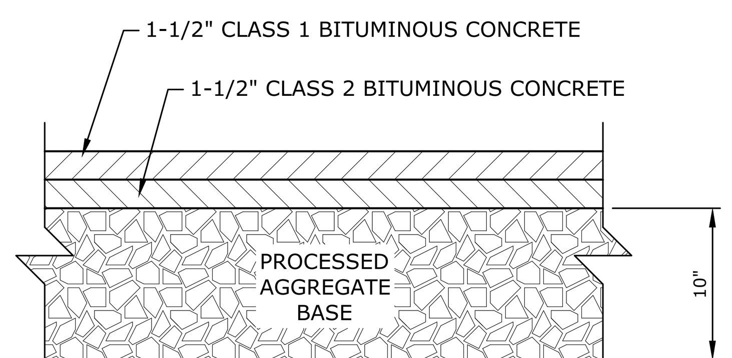
MODULAR BLOCK RETAINING WALL
NO SCALE



NOTE:

1. CONSTRUCT CURBING IN SECTIONS NOT TO EXCEED 10 FEET IN LENGTH, SUCH THAT THE CURBING JOINTS ALIGN WITH JOINTS IN THE CONCRETE PAVEMENT SLAB. NO SECTION SHALL BE LESS THAN 6 FEET IN LENGTH.

[illegible]
NO SCALE



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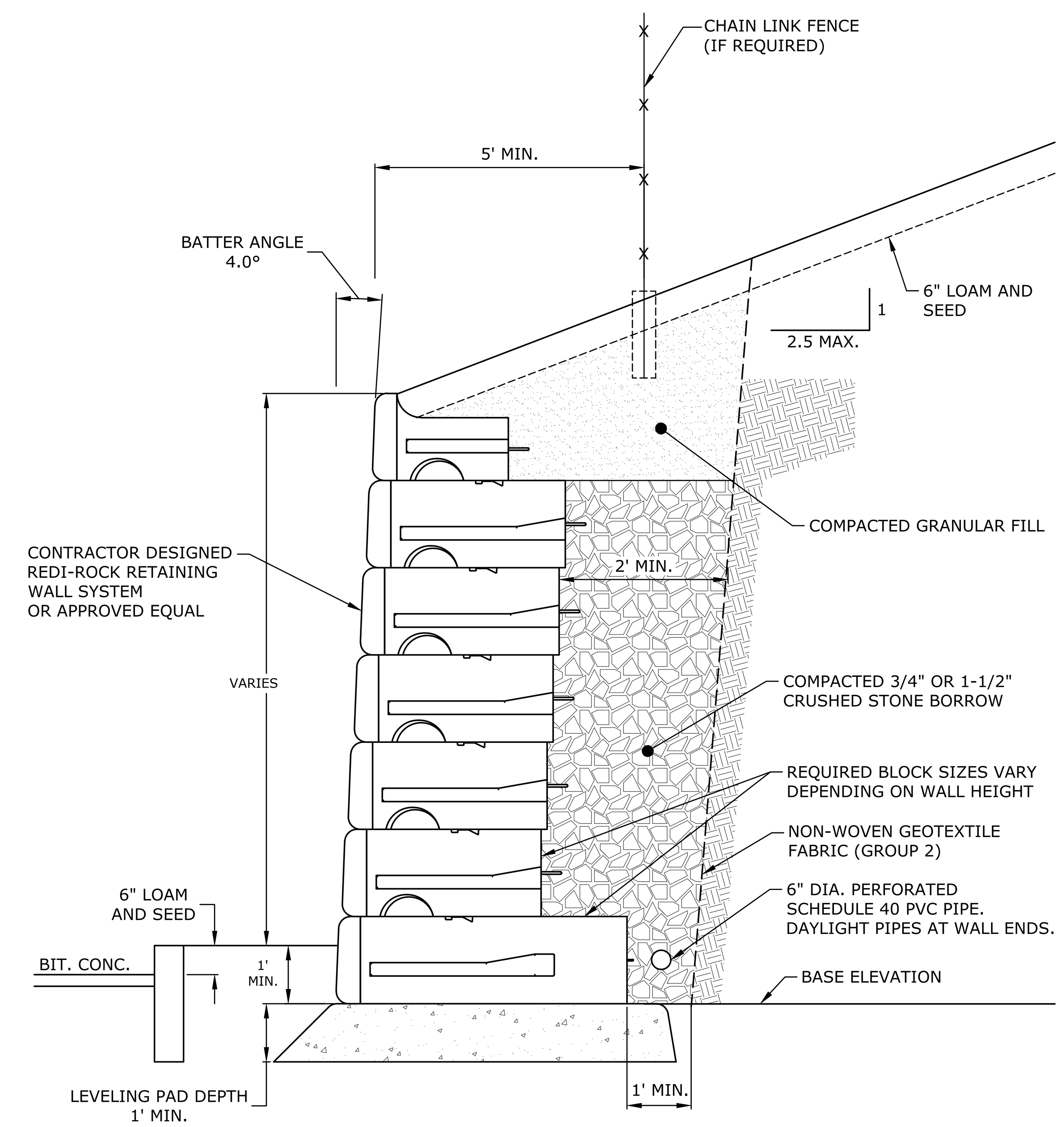
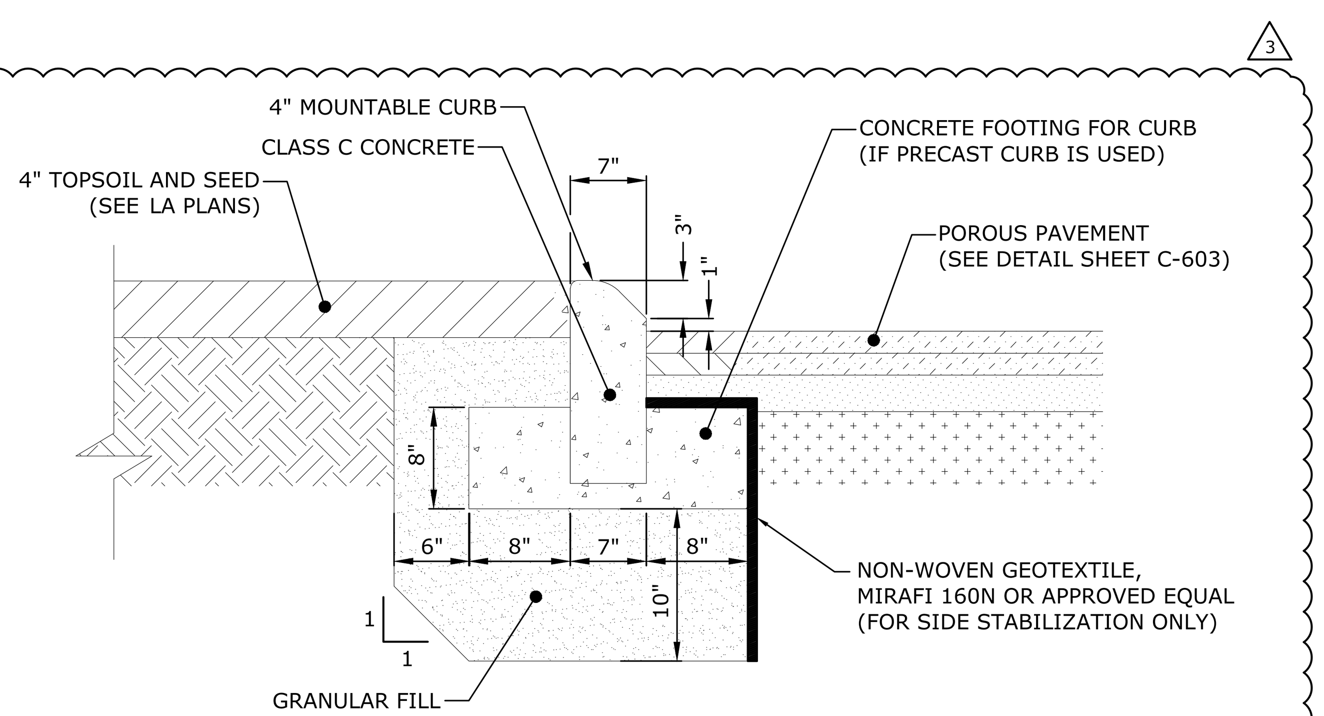


NOTE:

1. TEMPORARY EXCAVATIONS FOR WALL AND CRUSHED STONE PLACEMENT SHALL BE IN ACCORDANCE WITH OSHA STANDARDS. ADDITIONAL BACKFILL REQUIRED TO FILL EXCAVATIONS SHALL CONSIST OF COMPACTED GRANULAR FILL OR CRUSHED STONE EXCEPT AS NOTED.

[illegible]
NO SCALE



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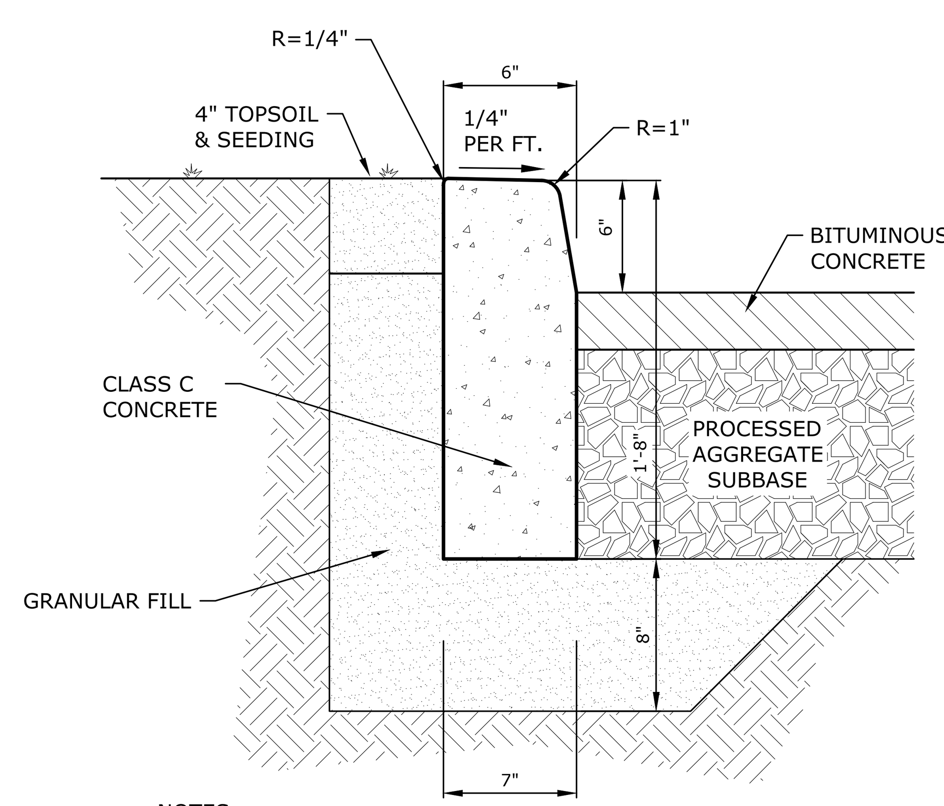

NOTES:

1. CONSTRUCT CURBING IN SECTIONS NOT TO EXCEED 10 FEET IN LENGTH, SUCH THAT THE CURBING JOINTS ALIGN WITH JOINTS IN THE CONCRETE PAVEMENT SLAB. NO SECTION SHALL BE LESS THAN 6 FEET IN LENGTH.

[illegible]
NO SCALE

Last Saved: 8/24/2021
Plotted On:Aug 24, 2021-1:11pm By: SansoneM
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FDSPIN
141 DR, LLC

Wilton, Connecticut

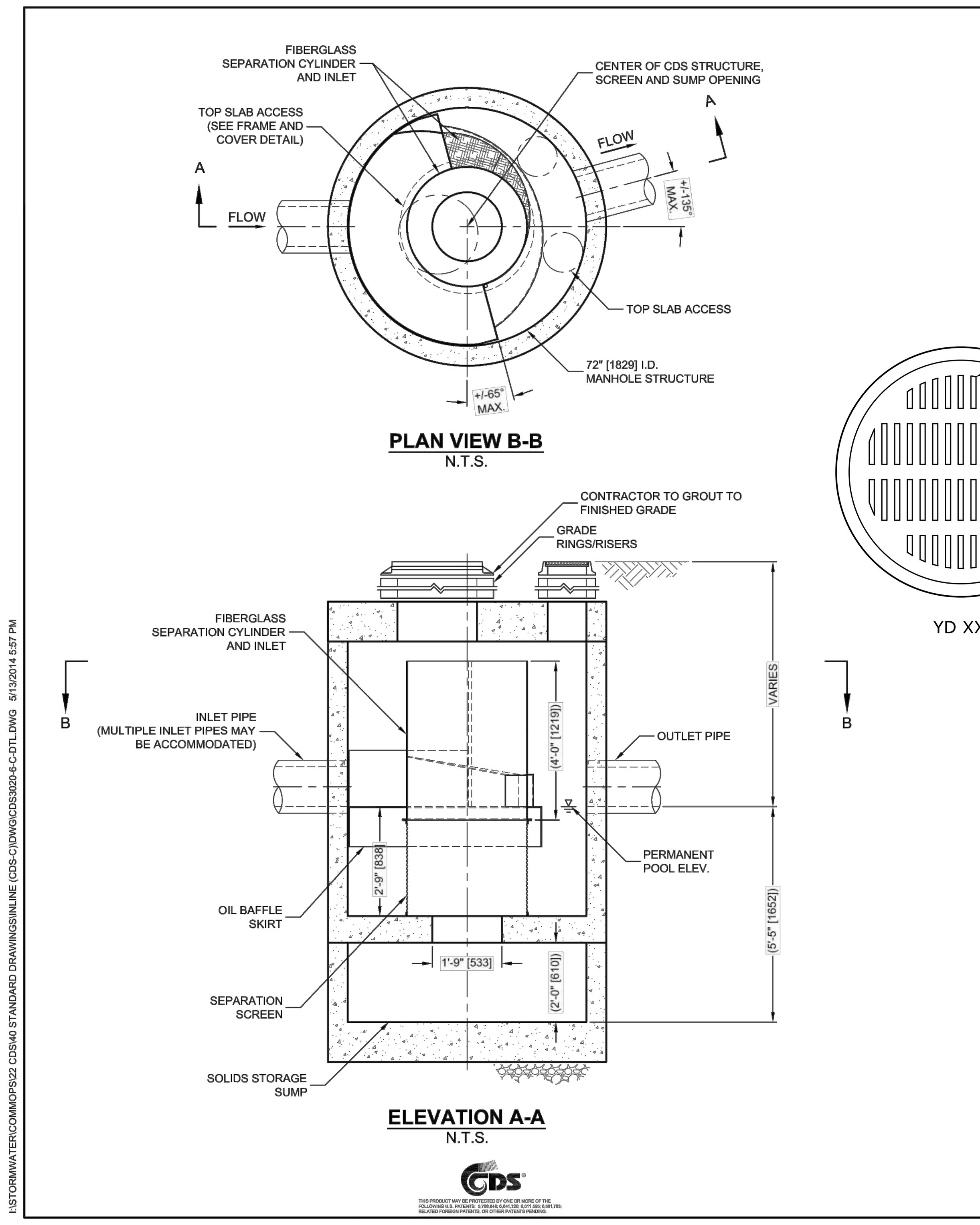
MARK	DATE	DESCRIPTION
3	8/24/2021	FIRE MARSHALL COMMENTS
2	8/12/2021	FIRE MARSHALL COMMENTS
1	7/15/2021	REV'D BLDG & SITE LAYOUT

PROJECT NO:	F0173-002
DATE:	06/07/2021
FILE:	F0173-02-C-601-DETL.dwg
DRAWN BY:	MDS
CHECKED:	EWL
APPROVED:	JWB

DETAILS - 2

SCALE: AS SHOWN

C-602



CDS3020-6-C DESIGN NOTES

CDS3020-6-C RATED TREATMENT CAPACITY IS 2.0 CFS [56.6 L/s], OR PER LOCAL REGULATIONS. MAXIMUM HYDRAULIC INTERNAL BYPASS CAPACITY IS 20.0 CFS [566 L/s]. IF THE SITE CONDITIONS EXCEED 20.0 CFS [566 L/s], AN UPSTREAM BYPASS STRUCTURE IS REQUIRED.

THE STANDARD CDS3020-6-C CONFIGURATION IS SHOWN. ALTERNATE CONFIGURATIONS ARE AVAILABLE AND ARE LISTED BELOW. SOME CONFIGURATIONS MAY BE COMBINED TO SUIT SITE REQUIREMENTS.

CONFIGURATION DESCRIPTION

- GRATED INLET ONLY (NO INLET PIPE)
- GRATED INLET WITH INLET PIPE OR PIPES
- CURB INLET ONLY (NO INLET PIPE)
- CURB INLET WITH INLET PIPE OR PIPES
- SEPARATE OIL BAFFLE (SINGLE INLET PIPE REQUIRED FOR THIS CONFIGURATION)
- SEDIMENT WEIR FOR NJDEP / NJCAT CONFORMING UNITS

SITE SPECIFIC DATA REQUIREMENTS

STRUCTURE ID				
WATER QUALITY FLOW RATE (CFS OR L/s)				*
PEAK FLOW RATE (CFS OR L/s)				*
RETURN PERIOD OF PEAK FLOW (YRS)				*
SCREEN APERTURE (2400 OR 4700)				*
PIPE DATA:	I.E.	MATERIAL		DIAMETER
INLET PIPE 1	*	*		*
INLET PIPE 2	*	*		*
OUTLET PIPE	*	*		*
RIM ELEVATION				*
ANTI-FLOTATION BALLAST		WIDTH		HEIGHT
		*		*

NOTES/SPECIAL REQUIREMENTS:

* PER ENGINEER OF RECORD

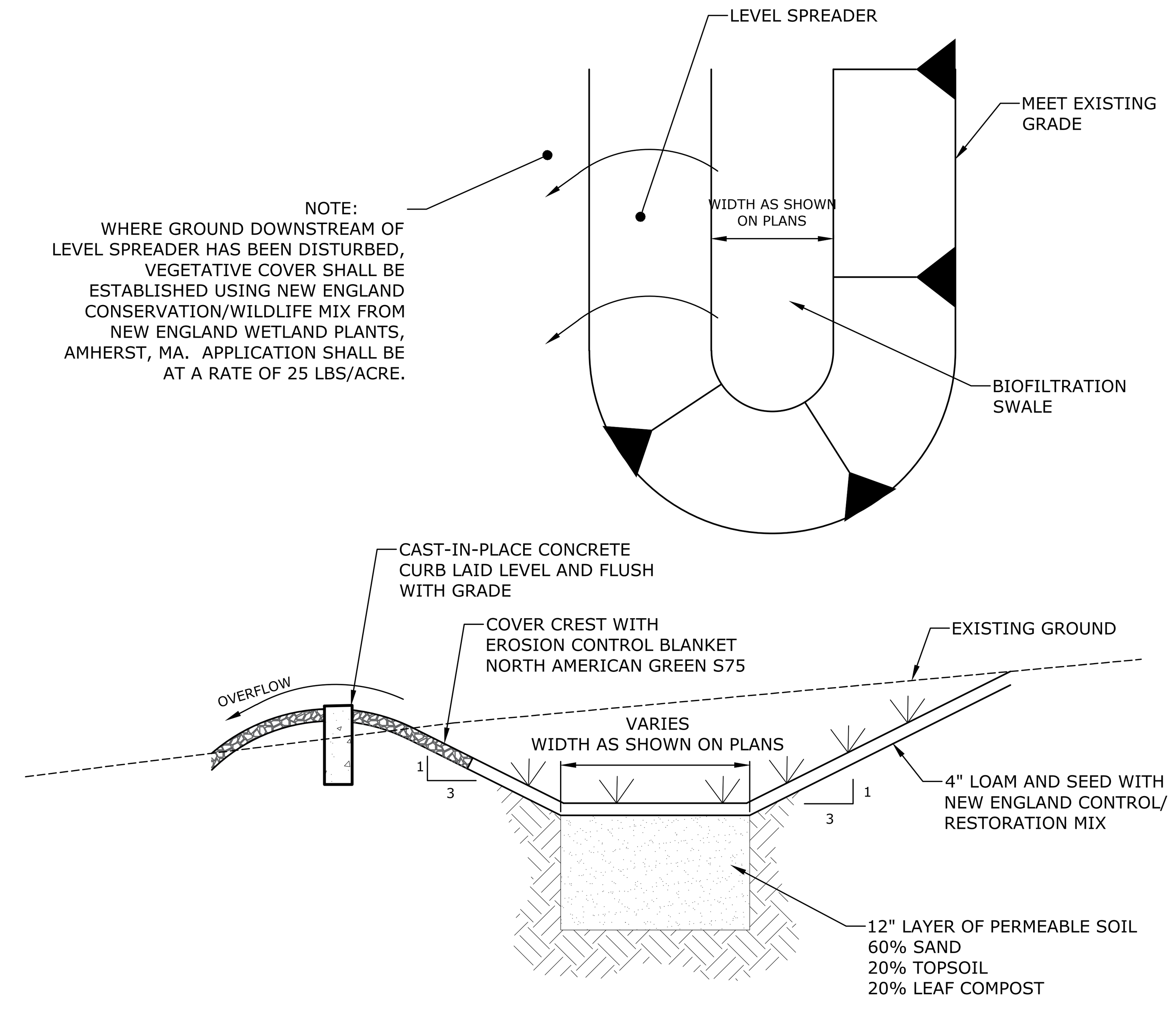
GENERAL NOTES
1. CONTECH TO PROVIDE ALL MATERIALS UNLESS NOTED OTHERWISE.
2. DIMENSIONS MARKED WITH ( ) ARE REFERENCE DIMENSIONS. ACTUAL DIMENSIONS MAY VARY.
3. FOR FABRICATION DRAWINGS WITH DETAILED STRUCTURE DIMENSIONS AND WEIGHTS, PLEASE CONTACT YOUR CONTECH ENGINEERED SOLUTIONS LLC REPRESENTATIVE. www.ContechES.com
4. CDS WATER QUALITY STRUCTURE SHALL BE IN ACCORDANCE WITH ALL DESIGN DATA AND INFORMATION CONTAINED IN THIS DRAWING.
5. STRUCTURE SHALL MEET AASHTO HS20 AND CASTINGS SHALL MEET HS20 (AASHTO M 306) LOAD RATING, ASSUMING GROUNDWATER ELEVATION AT, OR BELOW, THE OUTLET PIPE INVERT ELEVATION. ENGINEER OF RECORD TO CONFIRM ACTUAL GROUNDWATER ELEVATION.
6. PVC HYDRAULIC SHEAR PLATE IS PLACED ON SHELF AT BOTTOM OF SCREEN CYLINDER. REMOVE AND REPLACE AS NECESSARY DURING MAINTENANCE CLEANING.

INSTALLATION NOTES
A. ANY SUB-BASE, BACKFILL DEPTH, AND/OR ANTI-FLOTATION PROVISIONS ARE SITE-SPECIFIC DESIGN CONSIDERATIONS AND SHALL BE SPECIFIED BY ENGINEER OF RECORD.
B. CONTRACTOR TO PROVIDE EQUIPMENT WITH SUFFICIENT LIFTING AND REACH CAPACITY TO LIFT AND SET THE CDS MANHOLE STRUCTURE (LIFTING CLUTCHES PROVIDED).
C. CONTRACTOR TO ADD JOINT SEALANT BETWEEN ALL STRUCTURE SECTIONS, AND ASSEMBLE STRUCTURE.
D. CONTRACTOR TO PROVIDE, INSTALL, AND GROUT PIPES. MATCH PIPE INVERTS WITH ELEVATIONS SHOWN.
E. CONTRACTOR TO TAKE APPROPRIATE MEASURES TO ASSURE UNIT IS WATER TIGHT, HOLDING WATER TO FLOWLINE INVERT MINIMUM. IT IS SUGGESTED THAT ALL JOINTS BELOW PIPE INVERTS ARE GROUTED.

CONTECH ENGINEERED SOLUTIONS LLC
www.ContechES.com
9025 Centre Pointe Dr., Suite 400, West Chester, OH 45069
800-338-1122 513-645-7000 513-645-7993 FAX

CDS3020-6-C
INLINE CDS
STANDARD DETAIL

NO SCALE



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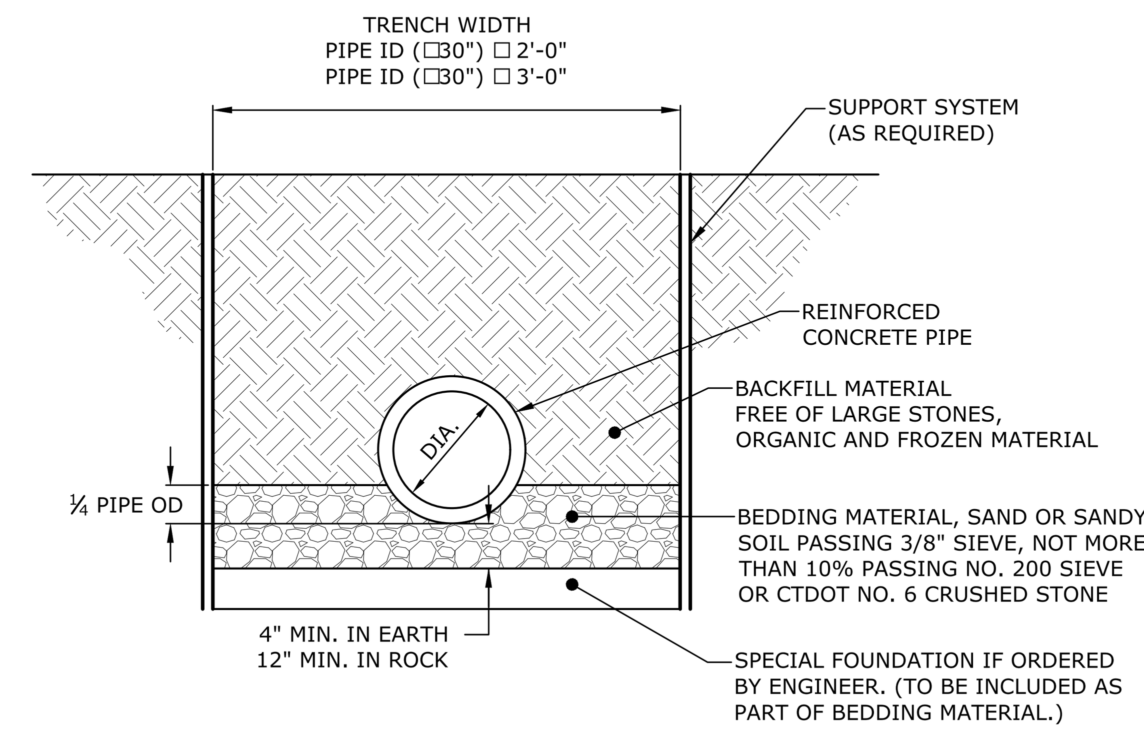

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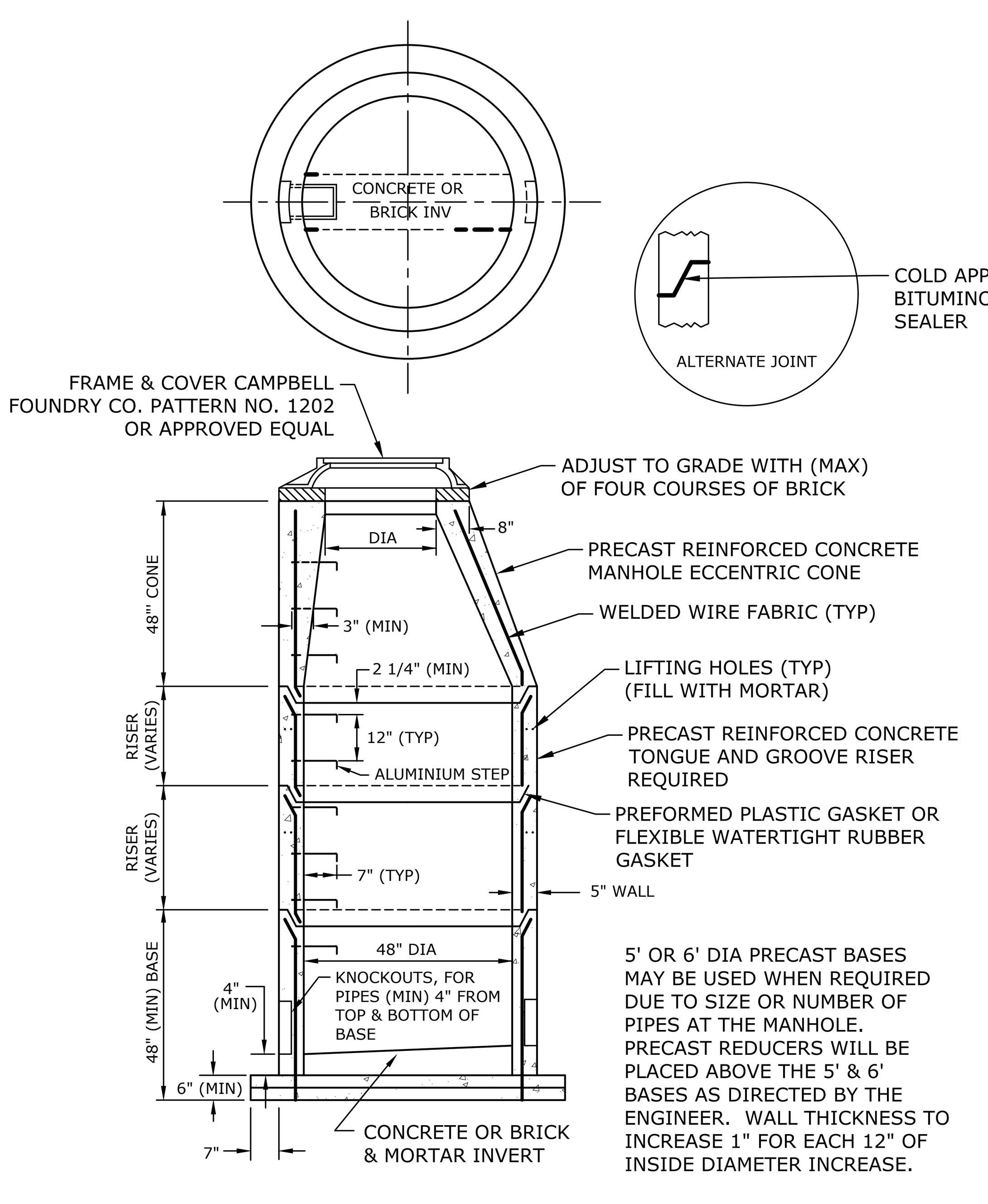
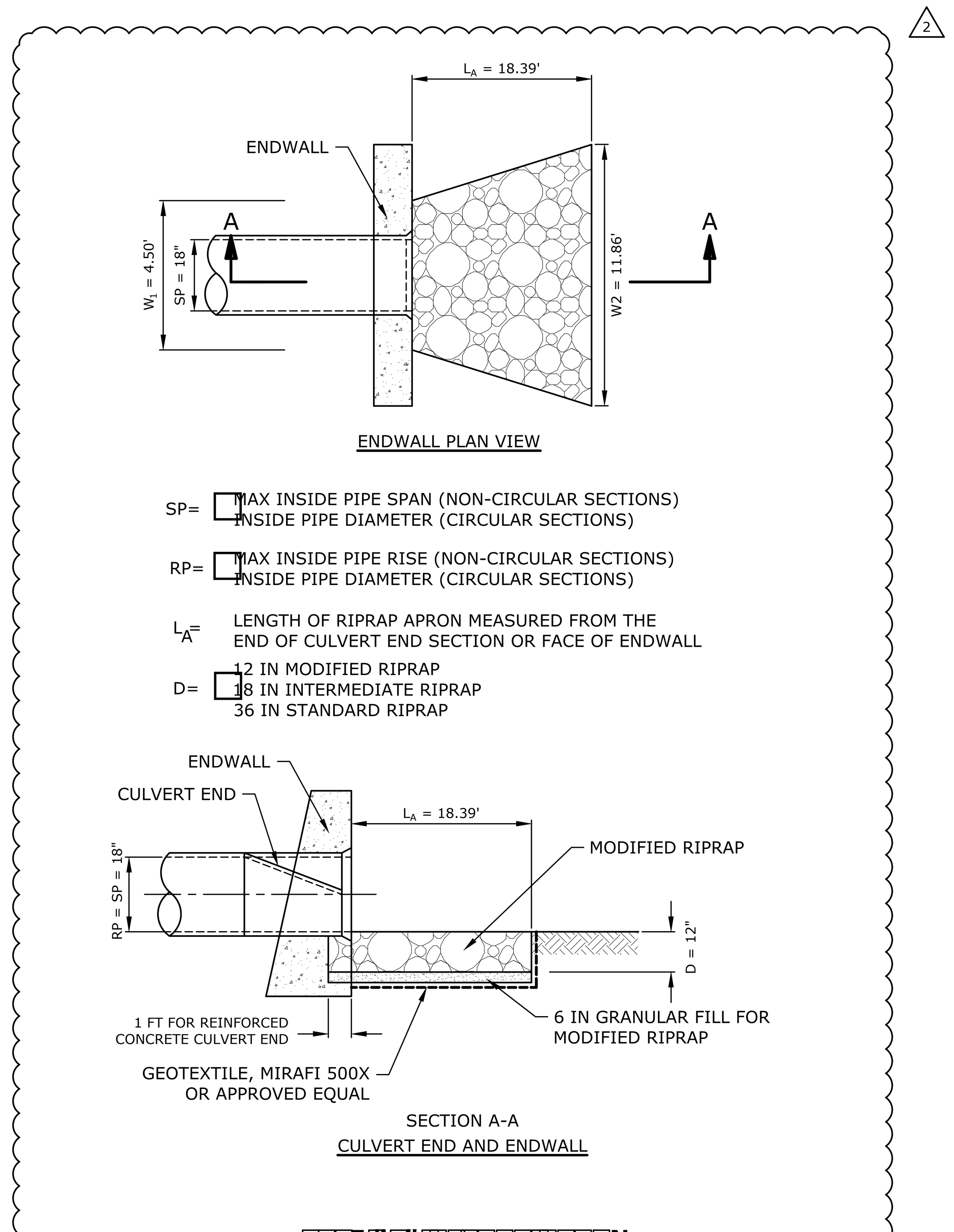


48" PRECAST MANHOLE
NO SCALE



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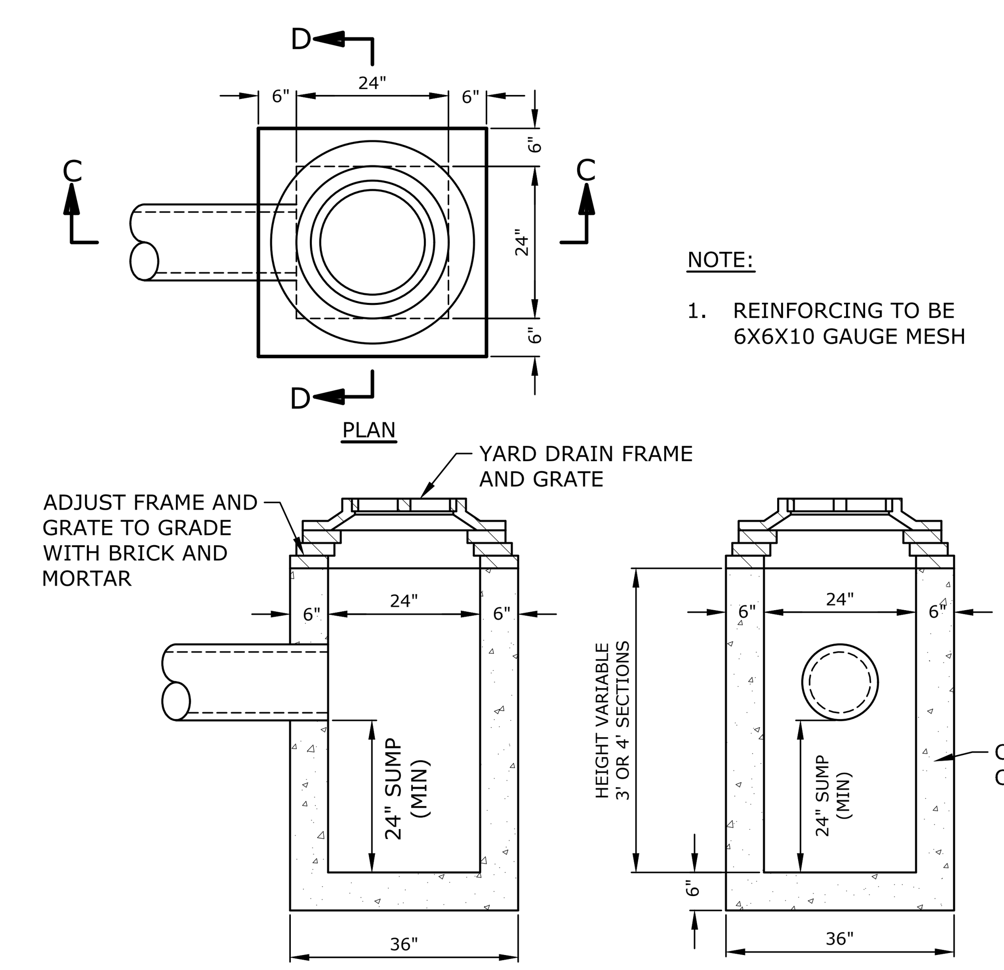

YARD DRAIN
NO SCALE

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FDSPIN
141 DR, LLC

Wilton, Connecticut

MARK	DATE	DESCRIPTION
2	10/8/2021	3RD PARTY REVIEW COMMENTS
1	7/15/2021	REV'D BLDG & SITE LAYOUT

PROJECT NO:	F0173-002
DATE:	06/07/2021
FILE:	F0173-02-C-601-DETL.dwg
DRAWN BY:	MDS
CHECKED:	EWL
APPROVED:	JWB

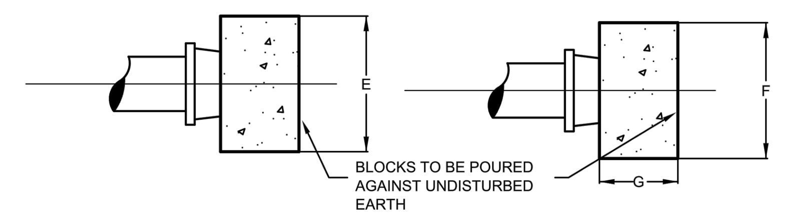
DETAILS - 5

SCALE: AS SHOWN

C-605

Last Saved: 10/8/2021
Plotted On:Oct 08, 2021-9:36am By: TAS
Tighe & Bond: J:\F\F0173 Fuller\002 141 Danbury Road\Drawings-Figures\Sheets\F0173-02-C-601-DETL.dwg

THRUST BLOCKS AT TEES, CAPS, PLUGS & VALVES (SD-14)



PLAN

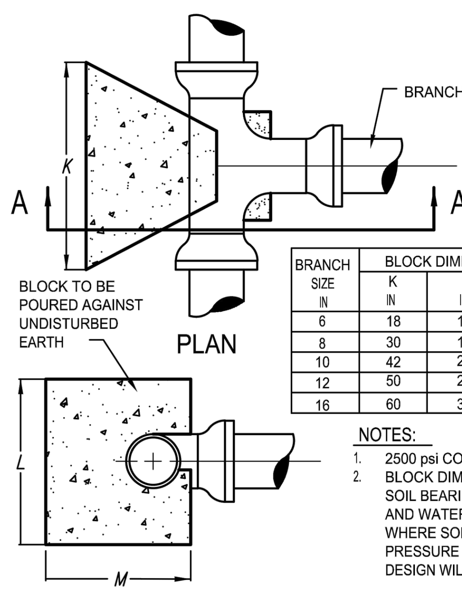
ELEVATION

NOTES:

1. 2500 psi CONCRETE TO BE USED
2. BLOCK DIMENSIONS ARE BASED UPON SOIL BEARING PRESSURE OF 2000 psi AND WATER PRESSURE OF 150 psi. WHERE SOIL BEARING IS LESS OR WATER PRESSURE IS GREATER, A SPECIAL DESIGN WILL BE REQUIRED.
3. FOR USE ON ABANDONED LINES AND DEAD ENDS WHERE NO EXTENSION IS CONTEMPLATED.

PIPE DIAM. IN	BLOCK DIMENSIONS E IN	F IN	G IN	CONCRETE VOLUME CU. YD.
6	20	16	12	0.09
8	28	20	12	0.15
10	30	24	12	0.19
12	42	30	14	0.40
16	52	42	18	0.85

CAPS, PLUGS AND VALVES



PLAN

SECTION AA

BRANCH SIZE IN	BLOCK DIMENSIONS K IN	L IN	M IN	CONCRETE VOLUME CU. YD.
6	18	16	12	0.09
8	30	18	12	1.15
10	42	20	12	0.24
12	50	24	16	0.42
16	60	36	24	1.12

NOTES:

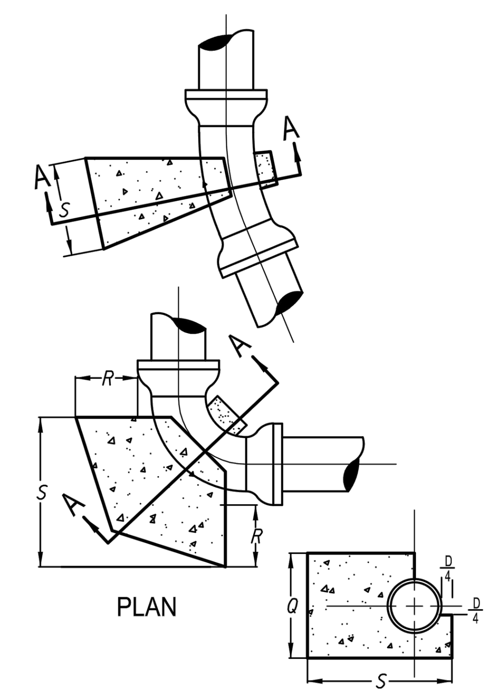
1. 2500 psi CONCRETE TO BE USED
2. BLOCK DIMENSIONS ARE BASED UPON SOIL BEARING PRESSURE OF 2000 psi AND WATER PRESSURE OF 150 psi. WHERE SOIL BEARING IS LESS OR WATER PRESSURE IS GREATER, A SPECIAL DESIGN WILL BE REQUIRED.

TEES

AQUARION Water Company
Stewards of the Environment

THRUST BLOCKS
AT TEES, CAPS, PLUGS & VALVES
NOT TO SCALE
SD-14

THRUST BLOCKS AT HORIZONTAL BENDS (SD-15)



PLAN

SECTION AA

PIPE DIAM. IN	BEND	BLOCK DIMENSIONS S IN.	Q IN.	R IN.	CONCRETE VOLUME CU. YD.
16	90	48	48	48	2.37
	45	48	34	20	0.70
	22 1/2	42	20	18	0.32
	11 1/4				SEE NOTE 3
12	90	36	36	36	1.00
	45	36	24	18	0.33
	22 1/2	28	18	12	0.13
	11 1/4				SEE NOTE 3
10	90	30	30	30	0.60
	45	30	20	18	0.23
	22 1/2	22	16	12	0.09
	11 1/4				SEE NOTE 3
8	90	24	24	24	0.30
	45	24	16	12	0.20
	22 1/2	18	12	12	0.11
	11 1/4				SEE NOTE 3
6	90	18	18	18	0.25
	45	18	12	12	0.11
	22 1/2	12	12	12	0.07
	11 1/4				SEE NOTE 3

NOTES:

1. 2500 psi CONCRETE TO BE USED
2. BLOCK DIMENSIONS ARE BASED UPON SOIL BEARING PRESSURE OF 2000 psi AND WATER PRESSURE OF 150 psi. WHERE SOIL BEARING IS LESS OR WATER PRESSURE IS GREATER, A SPECIAL DESIGN WILL BE REQUIRED.
3. SEE SAG VERTICAL (ABOVE)

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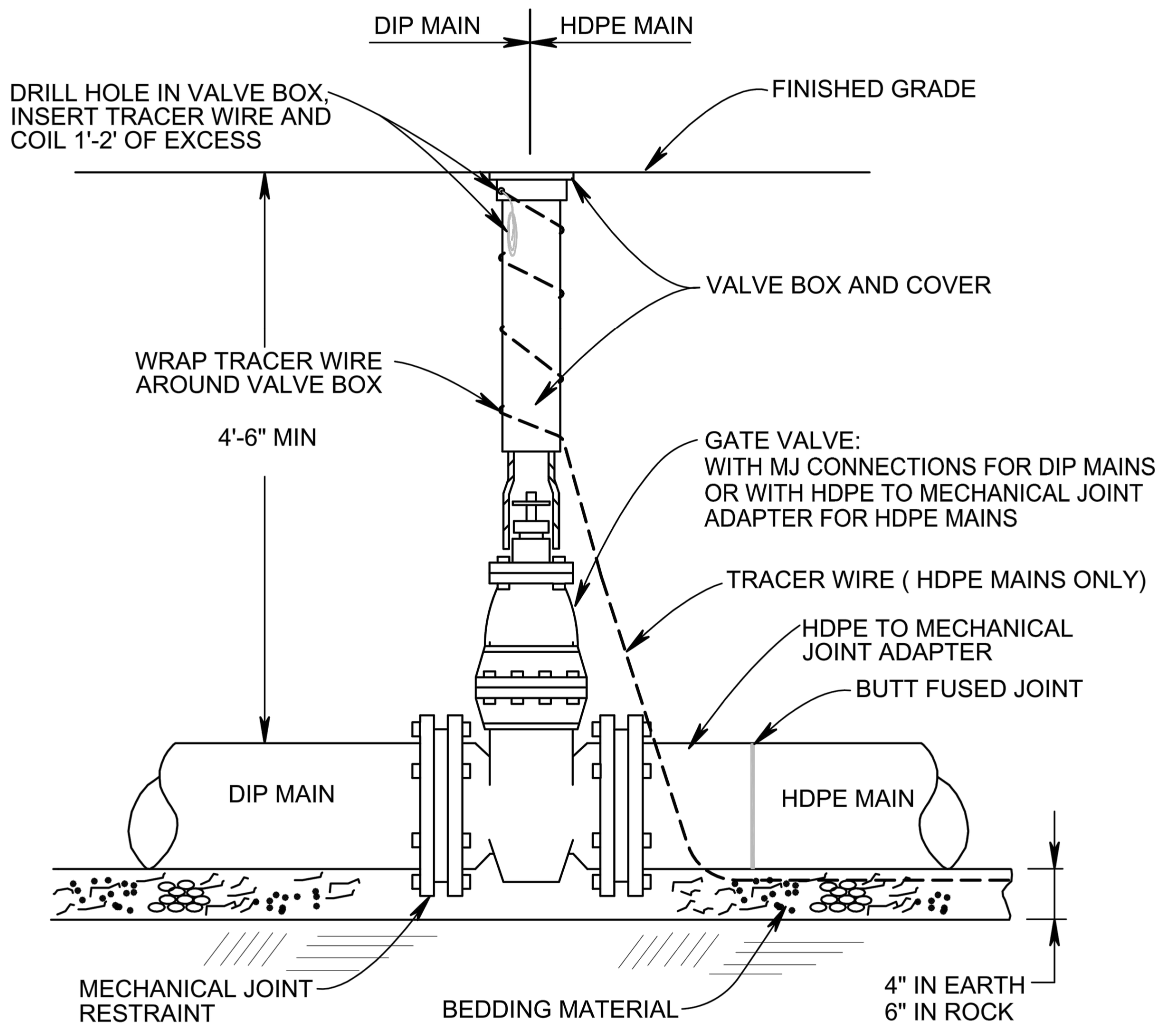
Stewards of the Environment

THRUST BLOCKS
AT HORIZONTAL BENDS
NOT TO SCALE
SD-15

GATE VALVE (SD-2)



NOTE: ONLY INSTALLED ON MAINS 8" AND SMALLER

NOTE: FOR CONTINUOUS HDPE MAINS, INSTALL TRACER WIRE UNDER ALL VALVES AND FITTINGS. FOR TERMINATION POINTS, INSTALL TRACER WIRE AROUND VALVE BOXES AS SHOWN ABOVE.

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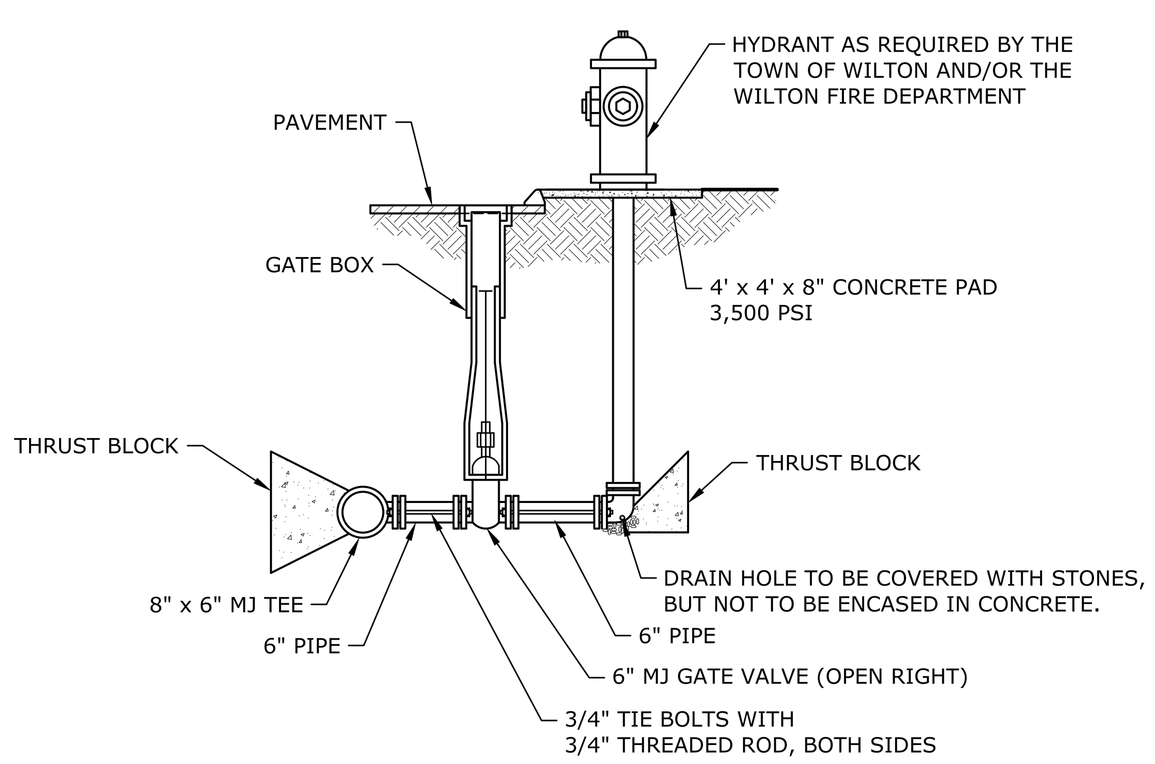
GATE VALVE
NOT TO SCALE
SD-2

Hydrant detail

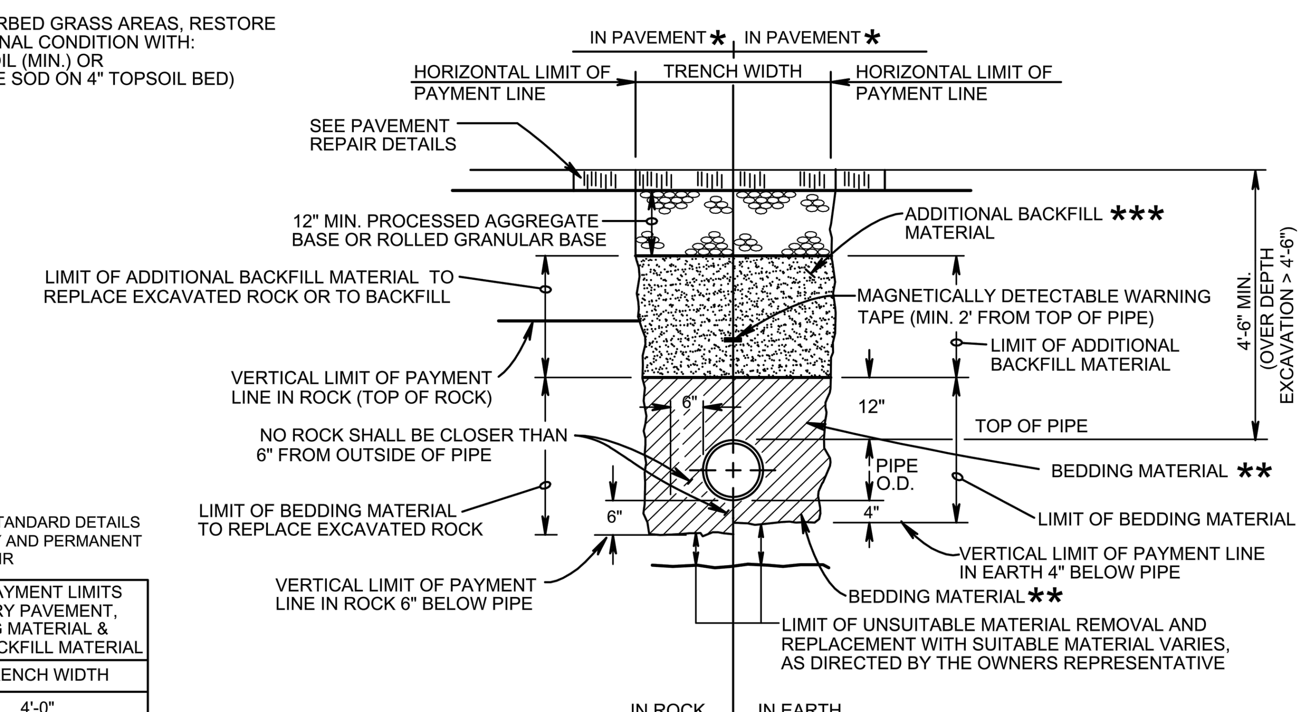
2



NO SCALE

TYPICAL TRENCH DETAIL (SD-1)

* IN DISTURBED GRASS AREAS, RESTORE TO ORIGINAL CONDITION WITH:
2" TOPSOIL (MIN.) OR
SOD (LIVE SOD ON 4" TOPSOIL BED)



REFER TO THE STANDARD DETAILS FOR TEMPORARY AND PERMANENT PAVEMENT REPAIR

HORIZONTAL PAYMENT LIMITS FOR TEMPORARY PAVEMENT, ROCK, BEDDING MATERIAL & ADDITIONAL BACKFILL MATERIAL	
PIPE SIZE	TRENCH WIDTH
6"	4'-0"
8"	4'-0"
12"	4'-0"
16"	4'-0"
20"	5'-0"
24"	5'-0"
30"	6'-0"
36"	6'-0"

NOTE: IF TRENCH BOXES ARE USED ADD 2' TO ALL TRENCH WIDTHS

** FOR DIP: NO STONES LARGER THAN 4", NO STONES WITHIN 4" OF PIPE, THOROUGHLY COMPACTED
FOR HDPE: NO STONES LARGER THAN 3/4", NO STONES WITHIN 4" OF PIPE, THOROUGHLY COMPACTED

*** (NO STONES LARGER THAN 12") (COMPACTED IN 12" LIFTS)

AQUARION Water Company
Stewards of the Environment

TYPICAL TRENCH DETAIL
NOT TO SCALE
SD-1

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8/24/21

8/24/21

FDSPIN
141 DR, LLC

Wilton, Connecticut

MARK	DATE	DESCRIPTION
2	8/24/2021	FIRE MARSHALL COMMENTS
1	7/15/2021	REV'D BLDG & SITE LAYOUT

PROJECT NO:	F0173-002
DATE:	06/07/2021
FILE:	F0173-02-C-601-DETL.dwg
DRAWN BY:	MDS
CHECKED:	EWL
APPROVED:	JWB

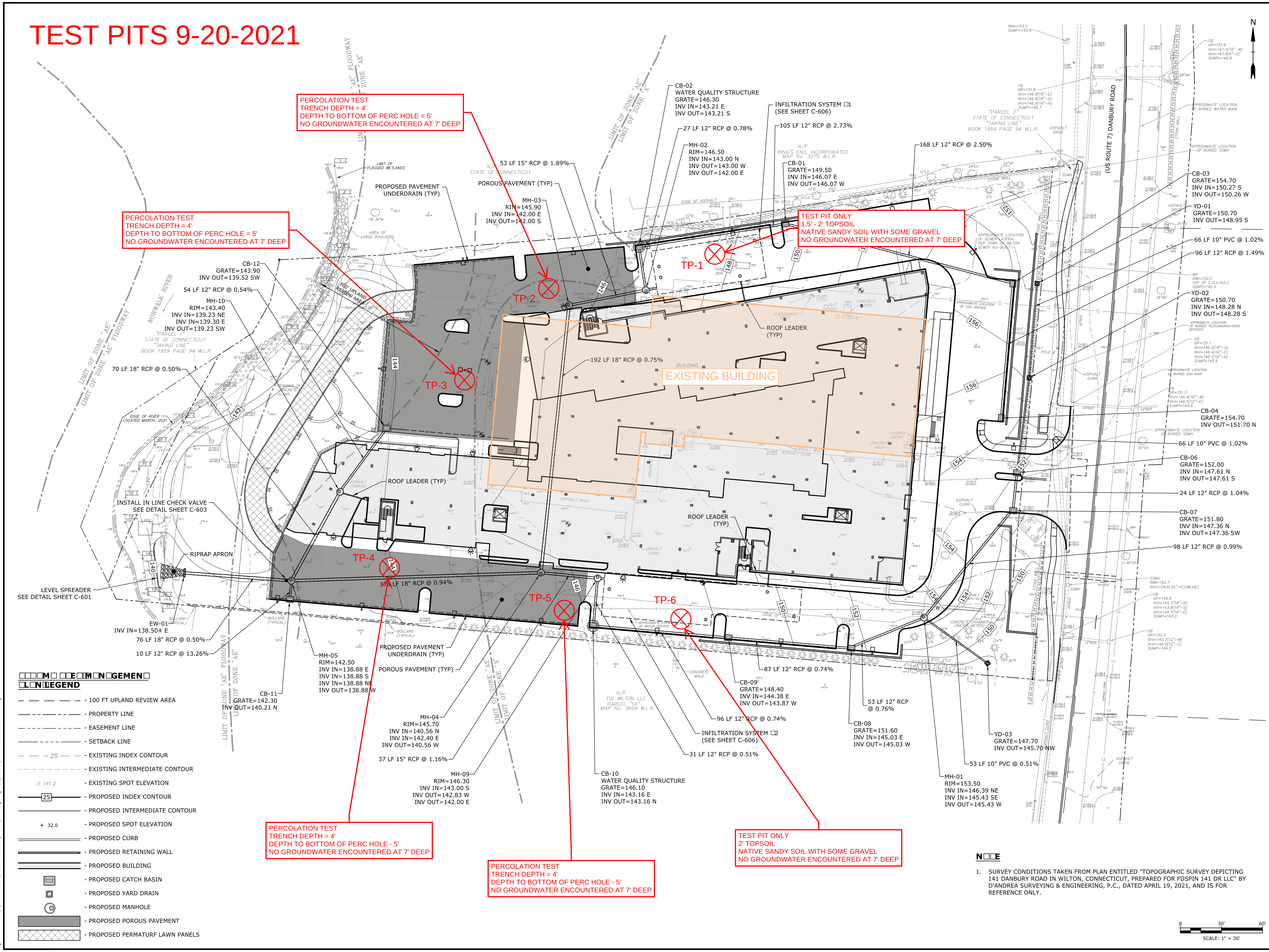
DETAILS - 8

SCALE: AS SHOWN

C-608

Site Soils Information

1. Test Pit Location Map
2. Percolation Test Worksheets
3. Test Pit Description & Notes



Tighe&Bond
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FDSPIN
141 DR, LLC

Wilton, Connecticut

MARK	DATE	DESCRIPTION
1	7/15/2021	REV'D BLDG & SITE LAYOUT

PROJECT NO:	F0173-002
DATE:	06/07/2021
FILE:	F0173-02-C-301-STRM.dwg
DRAWN BY:	MDS
CHECKED:	EWL
APPROVED:	JWB

STORMWATER
MANAGEMENT PLAN

SCALE: 1" = 30'

C-301

Tighe&Bond
Engineers | Environmental Specialists

Project Name: **141 Danbury Road**
Project Number: **F0173-02**
Project Location: **Wilton, CT**
Description: **Percolation Test**
Performed By: **TAS** Date: **9/20/2021**
Checked By: **EWL**

Perc Hole: **TP-4**
Location: Southwest of Existing Building (in parking area)
Diameter: 12"

Time	Δ Time (min)	Depth (in)	Drop (in)	Rate (in/min)	Rate (in/hr)	Comments
9:55 AM						Pre-soak
						Refilled and Start Test
10:25 AM		4.50				
10:35 AM	10.0	4.50	0.00	0.0	0.0	
10:40 AM	5.0	4.50	0.00	0.0	0.0	
						Dig Test Pit +1' Deeper
						Trench Depth = 4'
						Depth to Bottom of Hole = 5'
11:35 AM						Pre-soak
12:10 PM		4.50				Refilled and Start Test
12:20 PM	10.0	4.75	0.25	0.025	1.5	
12:30 PM	10.0	5.00	0.25	0.025	1.5	
12:40 PM	10.0	5.50	0.50	0.050	3.0	
12:45 PM	5.0	5.75	0.25	0.050	3.0	End Test

Result **Avg. Percolation Rate** **2.25** **in/hr**

Notes:
Fill beneath bituminous pavement, approximately 3.5' below surface. Very course material with large boulders.
Sandy soil beneath fill. No groundwater observed at a depth of 7' below surface.

Project Name: **141 Danbury Road**
Project Number: **F0173-02**
Project Location: **Wilton, CT**
Description: **Percolation Test**
Performed By: **TAS** Date: **9/20/2021**
Checked By: **EWL**

Perc Hole: **TP-3**
Location: West of Existing Building (in parking area)
Diameter: 12"

Time	Δ Time (min)	Depth (in)	Drop (in)	Rate (in/min)	Rate (in/hr)	Comments
10:20 AM						Pre-soak
						Refilled and Start Test
10:55 AM		8.75				
11:00 AM	5.0	10.25	1.50	0.3	18.0	
11:05 AM	5.0	11.25	1.00	0.2	12.0	
						Refilled and Start Test
11:08 AM		8.50				
11:10 AM	2.0	9.25	0.75	0.4	22.5	End Test

Result **Avg. Percolation Rate** **17.5** **in/hr**

Notes:
Fill beneath bituminous pavement, approximately 3.5' below surface. Very course material with large boulders.
Sandy soil beneath fill. No groundwater observed at a depth of 7' below surface.

Tighe&Bond
Engineers | Environmental Specialists

Project Name: **141 Danbury Road**
Project Number: **F0173-02**
Project Location: **Wilton, CT**
Description: **Percolation Test**
Performed By: **TAS** Date: **9/20/2021**
Checked By: **EWL**

Perc Hole: **TP-5**
Location: South of Existing Building, West of Hydrant (in grassy area)
Diameter: 12"

Time	Δ Time (min)	Depth (in)	Drop (in)	Rate (in/min)	Rate (in/hr)	Comments
12:35 PM						Pre-soak
						Refilled and Start Test
1:10 PM		3.75				
1:30 PM	20.0	6.75	3.00	0.15	9.0	
1:35 PM	5.0	7.50	0.75	0.15	9.0	
1:40 PM	5.0	8.25	0.75	0.15	9.0	
1:45 AM	5.0	9.00	0.75	0.15	9.0	End Test

Result **Avg. Percolation Rate** **9.0** **in/hr**

Tighe&Bond
Engineers | Environmental Specialists

Project Name: **141 Danbury Road**
Project Number: **F0173-02**
Project Location: **Wilton, CT**
Description: **Percolation Test**
Performed By: **TAS** Date: **9/20/2021**
Checked By: **EWL**

Perc Hole: **TP-2**
Location: North of Existing Building (near NW Corner, in grassy area)
Diameter: 12"

Time	Δ Time (min)	Depth (in)	Drop (in)	Rate (in/min)	Rate (in/hr)	Comments
2:20 PM						Pre-soak
						Refilled and Start Test
2:50 PM		3.00				
2:55 PM	5.0	3.75	0.75	0.15	9.0	
3:00 PM	5.0	4.50	0.75	0.15	9.0	
3:05 AM	5.0	5.25	0.75	0.15	9.0	End Test

Result **Avg. Percolation Rate** **9.0** **in/hr**

Tighe&Bond
Engineers | Environmental Specialists

Project Name: **141 Danbury Road**
Project Number: **F0173-02**
Project Location: **Wilton, CT**
Description: **Test Pits**
Prepared By: **TAS** Date: **9/20/2021**

<u>Test Pit #1</u>

Location: North of Existing Building in Grassy Area

0' - 2'	Topsoil and dark brown, fine to coarse sand with some gravel
2' - 7'	Dark brown fine to course sand with some gravel
	No Groundwater Observed

<u>Test Pit #2</u>

Location: North of Existing Building (near NW Corner) in Grassy Area

0' - 2'	Topsoil and brown, fine to coarse sand with some gravel
2' - 6'	Dark brown fine to course sand with some gravel
6' - 7'	Grey-brown fine to course sand with some fine gravel
	No Groundwater Observed

<u>Test Pit #3</u>

Location: West of Existing Building in Parking Area

0' - 1'	Bituminous pavement and processed aggregate
1' - 4.5'	Fill - Brown fine to course sand and course gravel with large boulders
4.5' - 7'	Light brown fine to course sand
	No Groundwater Observed

<u>Test Pit #4</u>

Location: Southwest of Existing Building in Parking Area

0' - 1'	Bituminous pavement and processed aggregate
1' - 4'	Fill - Brown fine to course sand and course gravel with large boulders
4' - 7'	Light brown fine to course sand
	No Groundwater Observed

<u>Test Pit #5</u>

Location: South of Existing Building in Grassy Area

0' - 2'	Topsoil and dark brown, fine to coarse sand with some gravel
2' - 7'	Dark brown fine to coarse sand with some gravel
	No Groundwater Observed

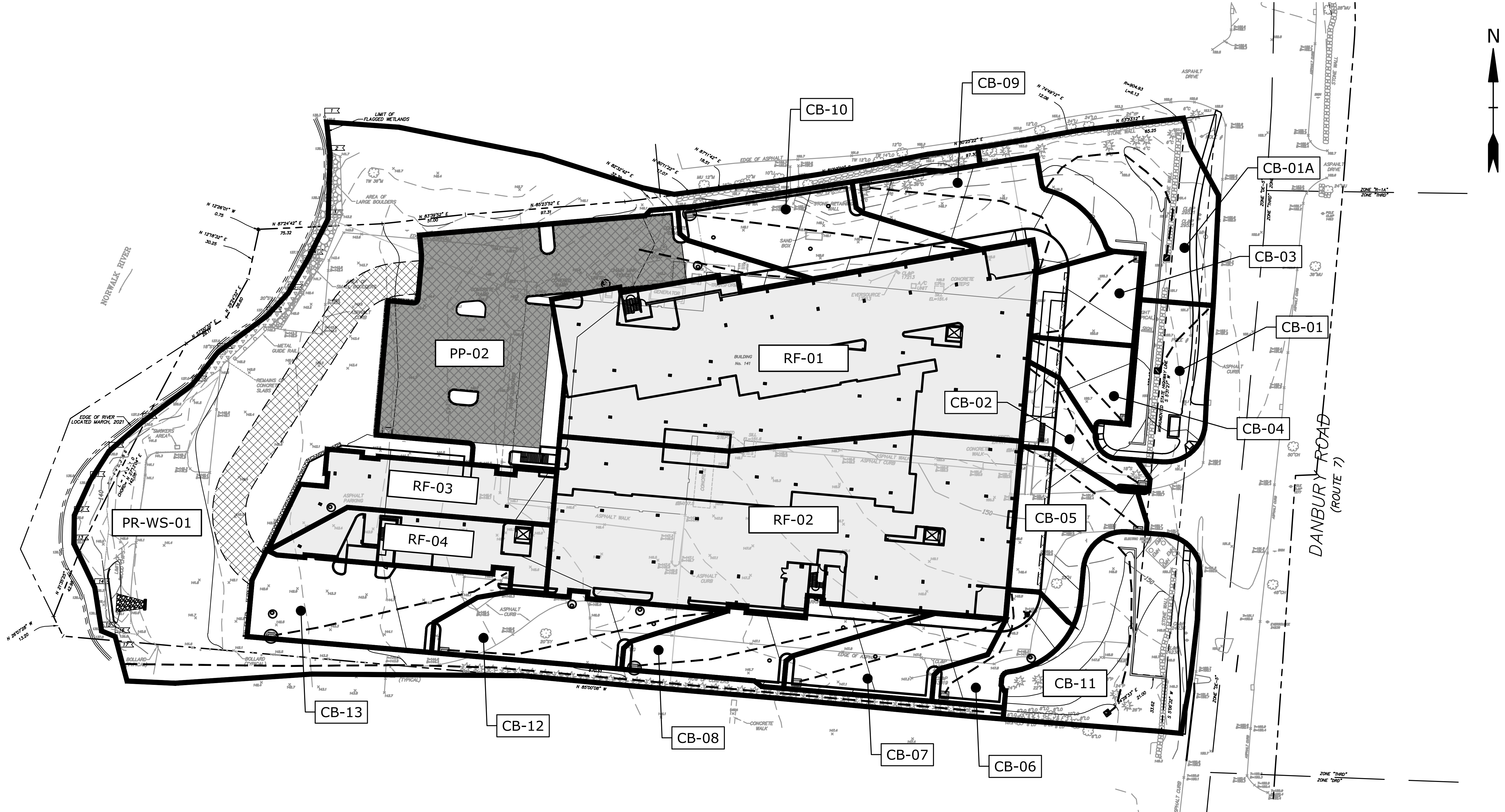
<u>Test Pit #6</u>

Location: South of Existing Building in Grassy Area

0' - 2'	Topsoil and brown, fine to coarse sand with some gravel
2' - 7'	Dark brown fine to coarse sand with some gravel
	No Groundwater Observed

Revised Watershed Map & Hydrologic Calculations

1. Watershed Map
2. Proposed CN & Tc Worksheet
3. Proposed Hydrograph Model
4. Peak Discharge Summary



LEGEND

WATERSHED BOUNDARY

Tc FLOW PATH

0 60' 120'

SCALE: 1" = 60'

141 DANBURY ROAD
WILTON, CONNECTICUT

PROPOSED WATERSHED MAP
AND Tc FLOW PATH
REVISED 09/27/2021

DATE: 07/09/2021
SCALE: 1" = 60'
FIGURE: WM-01

Tighe&Bond

Plotted On:Sep 24, 2021-12:13pm By: TAS
Tighe & Bond:J:\F\F0173 Fuller\002 141 Danbury Road\Design\Stormwater\F0173-02-C-WM-01.dwg

Name: **CB-12**
Location: Proposed Catch Basin - Parking Area South

Cover Type	Area (ac)	CN	A x CN
Pavement / Impervious	0.117	98	11.449
Landscaped and Lawns	0.002	69	0.158
			11.607

Total Area: **0.119** **CN:** **97**

Time of Concentration:

Sheet-Flow Travel Time					
Segment ID	**"n"**	**P_2 (in)**	**Flow Length (ft)**	**Slope (ft/ft)**	**Time (min)**
A-B	0.015	3.54	165	0.020	2.2

Total Tc (min) = **2.2**
Minimum Tc = **5.0**

Name: **CB-13**
Location: Proposed Catch Basin - Parking Area South

Cover Type	Area (ac)	CN	A x CN
Pavement / Impervious	0.149	98	14.628
Landscaped and Lawns	0.002	69	0.158
			14.786

Total Area: **0.152** **CN:** **98**

Time of Concentration:

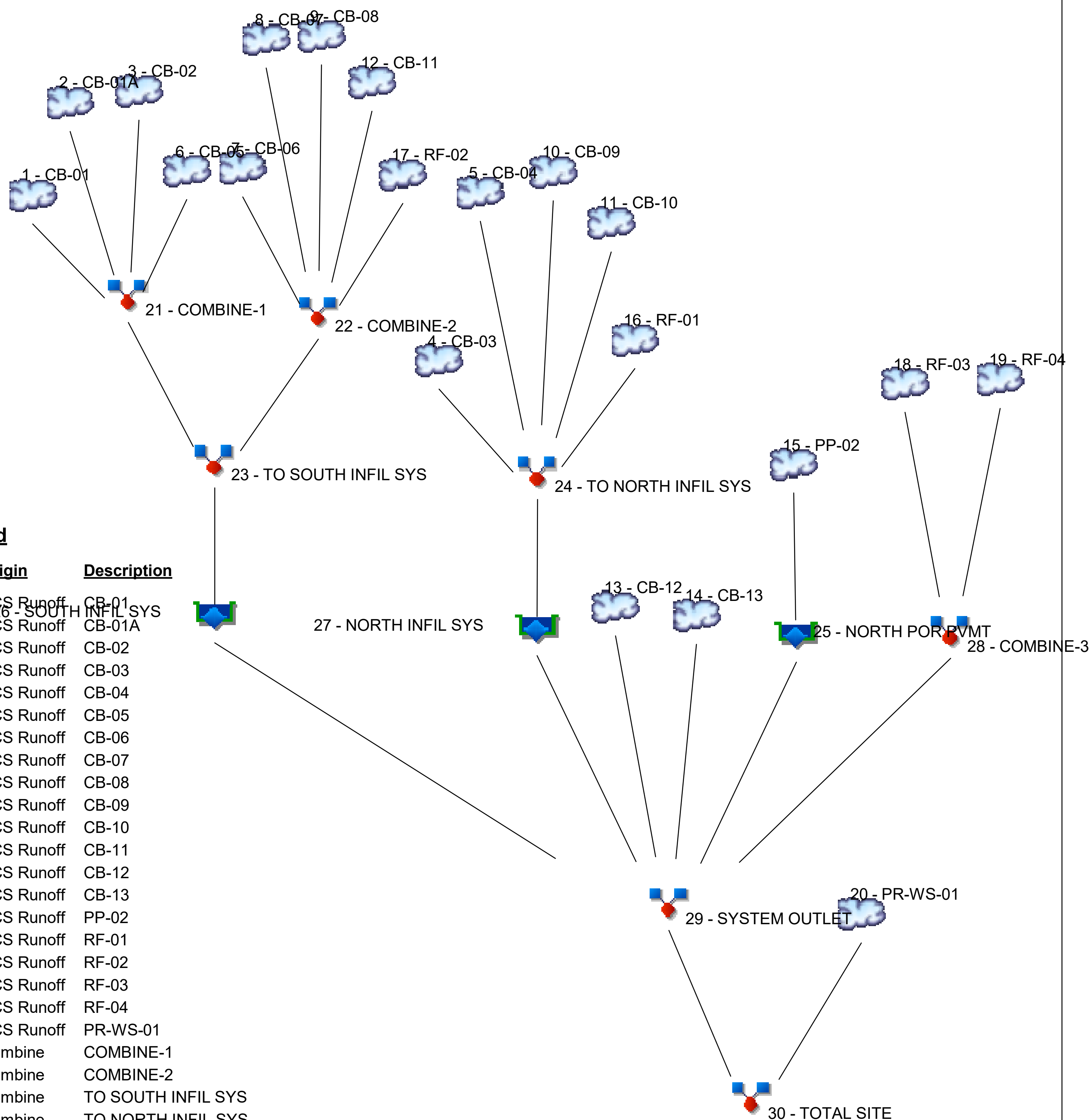
Sheet-Flow Travel Time					
Segment ID	**"n"**	**P_2 (in)**	**Flow Length (ft)**	**Slope (ft/ft)**	**Time (min)**
A-B	0.015	3.54	145	0.020	2.0

Total Tc (min) = **2.0**
Minimum Tc = **5.0**

References:
NRCS Technical Release 55
ConnDOT Drainage Manual, Chapter 6

Watershed Model Schematic

Hydraflow Hydrographs Extension for AutoCAD® Civil 3D® 2018 by Autodesk, Inc. v2018.3



Legend

Hyd.	Origin	Description
1	SCS Runoff	CB-01
2	SCS Runoff	CB-01A
3	SCS Runoff	CB-02
4	SCS Runoff	CB-03
5	SCS Runoff	CB-04
6	SCS Runoff	CB-05
7	SCS Runoff	CB-06
8	SCS Runoff	CB-07
9	SCS Runoff	CB-08
10	SCS Runoff	CB-09
11	SCS Runoff	CB-10
12	SCS Runoff	CB-11
13	SCS Runoff	CB-12
14	SCS Runoff	CB-13
15	SCS Runoff	PP-02
16	SCS Runoff	RF-01
17	SCS Runoff	RF-02
18	SCS Runoff	RF-03
19	SCS Runoff	RF-04
20	SCS Runoff	PR-WS-01
21	Combine	COMBINE-1
22	Combine	COMBINE-2
23	Combine	TO SOUTH INFIL SYS
24	Combine	TO NORTH INFIL SYS
25	Reservoir	NORTH POR PVMT
26	Reservoir	SOUTH INFIL SYS
27	Reservoir	NORTH INFIL SYS
28	Combine	COMBINE-3
29	Combine	SYSTEM OUTLET
30	Combine	TOTAL SITE

Hydrograph Return Period Recap

Hydraflow Hydrographs Extension for AutoCAD® Civil 3D® 2018 by Autodesk, Inc. v2018.3

Hyd. No.	Hydrograph type (origin)	Inflow hyd(s)	Peak Outflow (cfs)								Hydrograph Description
			1-yr	2-yr	3-yr	5-yr	10-yr	25-yr	50-yr	100-yr	
1	SCS Runoff	------	-------	0.128	-------	-------	0.269	0.364	0.436	0.514	CB-01
2	SCS Runoff	------	-------	0.195	-------	-------	0.475	0.671	0.822	0.987	CB-01A
3	SCS Runoff	------	-------	0.159	-------	-------	0.259	0.321	0.366	0.415	CB-02
4	SCS Runoff	------	-------	0.218	-------	-------	0.354	0.439	0.502	0.569	CB-03
5	SCS Runoff	------	-------	0.160	-------	-------	0.257	0.318	0.363	0.410	CB-04
6	SCS Runoff	------	-------	0.299	-------	-------	0.513	0.648	0.747	0.852	CB-05
7	SCS Runoff	------	-------	0.177	-------	-------	0.292	0.364	0.417	0.473	CB-06
8	SCS Runoff	------	-------	0.299	-------	-------	0.481	0.594	0.678	0.767	CB-07
9	SCS Runoff	------	-------	0.344	-------	-------	0.546	0.672	0.766	0.865	CB-08
10	SCS Runoff	------	-------	0.424	-------	-------	0.674	0.830	0.945	1.068	CB-09
11	SCS Runoff	------	-------	0.392	-------	-------	0.637	0.790	0.902	1.023	CB-10
12	SCS Runoff	------	-------	0.212	-------	-------	0.510	0.720	0.883	1.061	CB-11
13	SCS Runoff	------	-------	0.390	-------	-------	0.603	0.736	0.835	0.940	CB-12
14	SCS Runoff	------	-------	0.505	-------	-------	0.775	0.944	1.070	1.204	CB-13
15	SCS Runoff	------	-------	1.352	-------	-------	2.106	2.577	2.926	3.298	PP-02
16	SCS Runoff	------	-------	2.218	-------	-------	3.404	4.148	4.701	5.291	RF-01
17	SCS Runoff	------	-------	2.168	-------	-------	3.327	4.055	4.595	5.172	RF-02
18	SCS Runoff	------	-------	0.398	-------	-------	0.611	0.745	0.844	0.951	RF-03
19	SCS Runoff	------	-------	0.382	-------	-------	0.586	0.714	0.809	0.911	RF-04
20	SCS Runoff	------	-------	0.734	-------	-------	1.726	2.421	2.955	3.537	PR-WS-01
21	Combine	1, 2, 3, 6,	-------	0.722	-------	-------	1.409	1.865	2.210	2.583	COMBINE-1
22	Combine	7, 8, 9, 12, 17,	-------	3.147	-------	-------	5.059	6.276	7.186	8.161	COMBINE-2
23	Combine	21, 22	-------	3.869	-------	-------	6.468	8.142	9.396	10.74	TO SOUTH INFIL SYS
24	Combine	4, 5, 10, 11, 16,	-------	3.412	-------	-------	5.327	6.525	7.413	8.361	TO NORTH INFIL SYS
25	Reservoir	15	-------	0.000	-------	-------	0.000	0.031	0.105	0.200	NORTH POR PVMT
26	Reservoir	23	-------	0.241	-------	-------	2.347	3.888	5.328	7.056	SOUTH INFIL SYS
27	Reservoir	24	-------	0.583	-------	-------	2.771	4.442	5.575	6.513	NORTH INFIL SYS
28	Combine	18, 19,	-------	0.780	-------	-------	1.197	1.459	1.654	1.861	COMBINE-3
29	Combine	13, 14, 25, 26, 27, 28	-------	1.675	-------	-------	5.972	10.14	12.80	16.31	SYSTEM OUTLET
30	Combine	20, 29	-------	1.976	-------	-------	7.294	11.77	14.82	18.74	TOTAL SITE

Proj. file: J:\F\F0173 Fuller\002 141 Danbury Road\Design\Stormwater\F0173-02 Hydrograph - Proposed - REV 9-27-21.gpw | Friday, 09 / 24 / 2021

Tighe&Bond
Engineers | Environmental Specialists

Project Name: **141 Danbury Road**
Project Number: **F0173-02**
Project Location: **Wilton, CT**
Description: **Peak Discharge Summary**
Prepared By: **TAS** Date: **September 27, 2021**

Original Design Peak Discharges

Summary of Stormwater Peak Discharge (cfs)
Discharge Location: Norwalk River

	2 YR	10 YR	25 YR	50 YR	100 YR
Q_{pk} - Existing	7.662	13.50	17.25	20.05	23.05
Q_{pk} - Proposed	1.636	6.762	10.69	13.64	17.35
Reduction in Peak Flow	**78.6%**	**49.9%**	**38.0%**	**32.0%**	**24.7%**

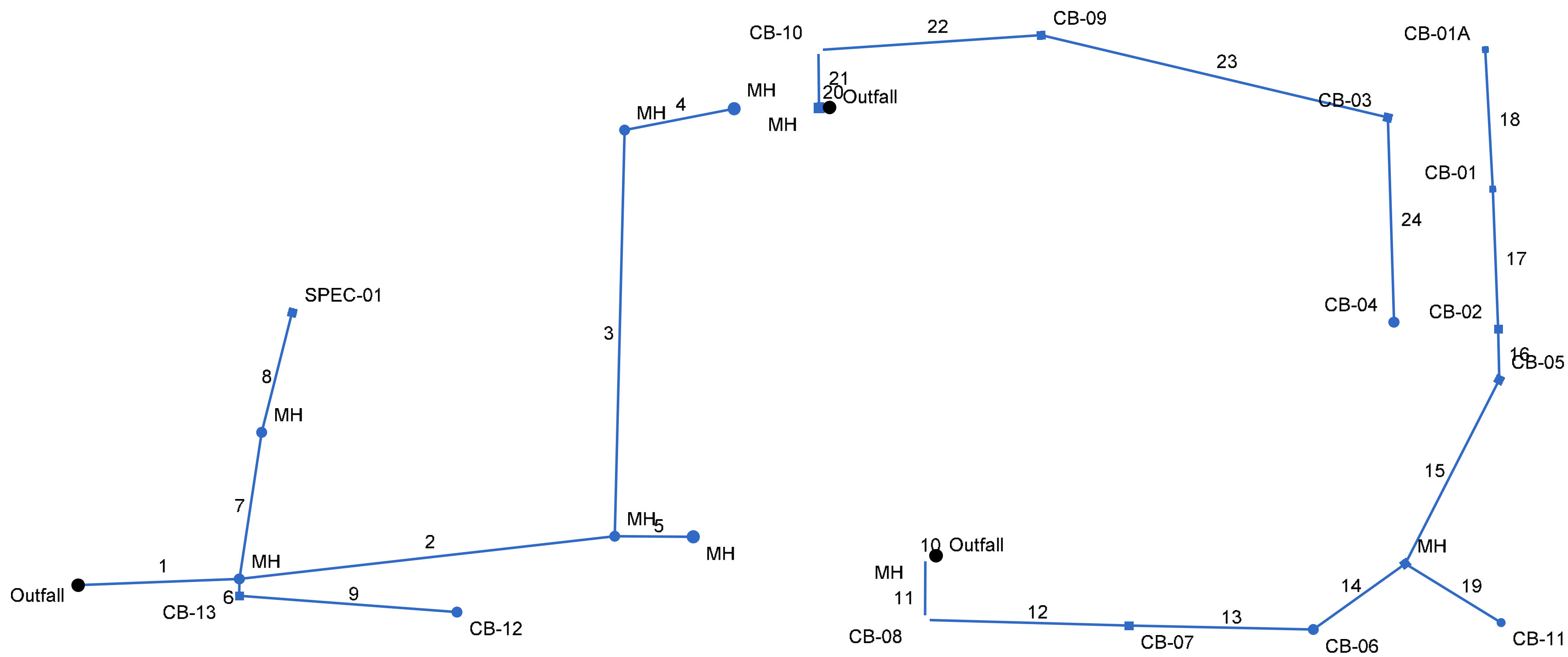
Revised Design Peak Discharges

Summary of Stormwater Peak Discharge (cfs)
Discharge Location: Norwalk River

	2 YR	10 YR	25 YR	50 YR	100 YR
Q_{pk} - Existing	7.662	13.50	17.25	20.05	23.05
Q_{pk} - Proposed	1.976	7.294	11.77	14.82	18.74
Reduction in Peak Flow	**74.2%**	**46.0%**	**31.8%**	**26.1%**	**18.7%**

Revised Storm Sewer Model & Riprap Apron Calculation

Hydraflow Storm Sewers Extension for Autodesk® AutoCAD® Civil 3D® Plan



Project File: F0173-02 Storm Sewers Model - REV 9-27-21.stm	Number of lines: 24	Date: 9/24/2021

Storm Sewer Tabulation

Station		Len	Drng Area		Rnoff coeff	Area x C		Tc		Rain (I)	Total flow	Cap full	Vel	Pipe		Invert Elev		HGL Elev		Grnd / Rim Elev		Line ID
Line	To Line		Incr	Total		Incr	Total	Inlet	Syst					Size	Slope	Dn	Up	Dn	Up	Dn	Up	
		(ft)	(ac)	(ac)	(C)			(min)	(min)	(in/hr)	(cfs)	(cfs)	(ft/s)	(in)	(%)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	
1	End	76.000	0.00	0.51	0.00	0.00	0.48	0.0	27.9	3.5	9.98	8.04	5.65	18	0.50	138.50	138.88	140.44	141.03	141.50	142.50	
2	1	178.000	0.00	0.00	0.00	0.00	0.00	0.0	1.3	0.0	8.30	11.05	4.70	18	0.94	138.88	140.56	141.52	142.47	142.50	145.79	
3	2	192.000	0.00	0.00	0.00	0.00	0.00	0.0	0.2	0.0	4.40	9.85	2.86	18	0.75	140.56	142.00	142.81	143.08	145.79	145.97	
4	3	52.600	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	4.40	9.65	4.27	15	1.90	142.00	143.00	143.24	143.85	145.97	146.50	
5	2	37.000	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	3.90	7.00	5.28	15	1.00	142.63	143.00	143.30	143.80	145.79	146.33	
6	1	8.000	0.15	0.27	0.94	0.14	0.25	5.0	6.4	7.7	1.96	4.09	2.49	12	1.12	138.88	138.97	141.52	141.54	142.50	142.30	
7	1	70.000	0.24	0.24	0.95	0.22	0.22	5.0	25.5	3.7	0.85	8.04	0.48	18	0.50	138.88	139.23	141.52	141.53	142.50	143.80	
8	7	58.500	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.03	2.72	0.04	12	0.50	139.23	139.52	141.53	141.53	143.80	143.90	
9	6	103.000	0.12	0.12	0.94	0.11	0.11	5.0	5.0	8.6	0.97	3.84	1.23	12	0.99	138.99	140.01	141.69	141.75	142.30	144.50	
10	End	5.000	0.00	0.97	0.00	0.00	0.54	0.0	16.7	4.7	2.55	0.00	3.25	12	0.00	142.00	142.00	144.03	144.05	146.33	146.33	
11	10	30.400	0.11	0.97	0.85	0.09	0.54	5.5	16.5	4.7	2.56	2.80	3.26	12	0.53	143.00	143.16	144.22	144.35	146.33	146.10	
12	11	96.000	0.10	0.86	0.83	0.08	0.45	5.0	15.9	4.8	2.16	3.32	2.76	12	0.74	143.16	143.87	144.60	144.87	146.10	148.30	
13	12	87.000	0.06	0.76	0.80	0.05	0.37	5.0	15.6	4.9	1.79	3.33	3.98	12	0.75	144.38	145.03	144.93	145.60	148.30	151.60	
14	13	53.300	0.00	0.70	0.00	0.00	0.32	0.0	15.3	4.9	1.56	3.34	3.54	12	0.75	145.03	145.43	145.60	145.96	151.60	153.50	
15	14	97.600	0.12	0.47	0.73	0.08	0.24	5.0	14.9	5.0	1.21	3.85	3.87	12	0.99	146.39	147.36	146.78	147.82	153.50	0.00	
16	15	23.900	0.05	0.36	0.82	0.04	0.16	5.0	14.7	5.1	0.79	3.87	2.60	12	1.00	147.36	147.60	147.82	147.97	0.00	152.50	
17	16	66.300	0.11	0.30	0.45	0.05	0.11	14.2	14.2	5.2	0.58	2.38	2.10	10	1.01	147.36	148.03	147.97	148.36	152.50	150.70	
18	17	66.000	0.19	0.19	0.33	0.06	0.06	7.8	7.8	7.0	0.45	2.39	2.42	10	1.02	148.03	148.70	148.36	148.99	150.70	150.70	
19	14	53.000	0.23	0.23	0.33	0.07	0.07	10.9	10.9	6.0	0.45	1.69	1.79	10	0.51	145.43	145.70	145.96	146.02	153.50	147.70	
20	End	5.000	0.00	0.40	0.00	0.00	0.33	0.0	7.7	7.1	2.33	0.00	2.96	12	0.00	142.00	142.00	143.95	143.97	146.50	146.50	
21	20	27.400	0.13	0.40	0.81	0.11	0.33	5.0	7.6	7.1	2.35	3.38	2.99	12	0.77	143.00	143.21	144.10	144.20	146.50	146.30	
22	21	105.100	0.14	0.26	0.86	0.12	0.22	5.0	7.0	7.4	1.64	6.36	2.93	12	2.72	143.21	146.07	144.41	146.61	146.30	149.70	
23	22	167.900	0.07	0.13	0.80	0.06	0.10	5.0	5.8	8.0	0.83	6.09	2.47	12	2.50	146.07	150.26	146.61	150.64	149.70	154.70	
24	23	96.700	0.05	0.05	0.84	0.04	0.04	5.0	5.0	8.6	0.38	4.71	1.90	12	1.49	150.26	151.70	150.64	151.95	154.70	154.70	

Project File: F0173-02 Storm Sewers Model - REV 9-27-21.stm

Number of lines: 24

Run Date: 9/24/2021

NOTES:Intensity = 38.51 / (Inlet time + 3.60) ^ 0.70; Return period =Yrs. 25 ; c = cir e = ellip b = box

Project Name: **141 Danbury Road**
Project Number: **F0173-02**
Project Location: **Wilton, CT**
Description: **Riprap Apron Calculation**
Prepared By: **TAS** Date: **July 9, 2021, rev. 9/27/21**

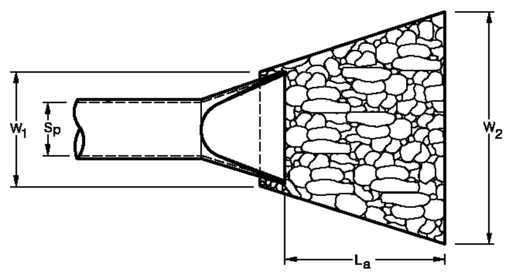
Riprap Apron

Invert Elevation =	138.50	ft
Tailwater Elevation =	140.44	ft
Tailwater Depth (TW) =	1.94	ft
Inside Pipe Diameter (S_p) =	1.50	ft
Pipe Discharge (Q) =	10.14	cfs
Outlet Velocity (V) =	5.65	ft/s

Apron Type

Type A Riprap Apron (Minimum Tailwater Condition) TW < $0.5R_p$
Type B Riprap Apron (Maximum Tailwater Condition) TW ≥ $0.5R_p$
TW = 1.94 > $0.5R_p$

Use Type B Apron



Apron Length

Type B Riprap Apron (Maximum Tailwater Condition) TW ≥ $0.5R_p$

$L_a = (3.0(Q-5)/Sp^{1.5})+10.0$

L_a = 18.39 ft

Apron Width

Type B Riprap Apron (Maximum Tailwater Condition) TW ≥ $0.5R_p$

$W_1 = 3*S_p$
$W_2 = 3*S_p+0.4L_a$

W_1 =	4.50	ft
W_2 =	11.86	ft

Riprap Specification

Outlet Velocity (V)=	0-8 ft/s	Modified
Outlet Velocity (V)=	8-10 ft/s	Intermediate
Outlet Velocity (V)=	10-14 ft/s	Standard

Outlet Velocity (V)= 5.65 ft/s Use Modified Riprap

Outlet protection has been designed in accordance with the Section 11.13 of the ConnDOT Drainage Manual

CONTECH®
ENGINEERED SOLUTIONS

CDS Guide
Operation, Design, Performance and Maintenance

CDS®

Using patented continuous deflective separation technology, the CDS system screens, separates and traps debris, sediment, and oil and grease from stormwater runoff. The indirect screening capability of the system allows for 100% removal of floatables and neutrally buoyant material without blinding. Flow and screening controls physically separate captured solids, and minimize the re-suspension and release of previously trapped pollutants. Inline units can treat up to 6 cfs, and internally bypass flows in excess of 50 cfs (1416 L/s). Available precast or cast-in-place, offline units can treat flows from 1 to 300 cfs (28.3 to 8495 L/s). The pollutant removal capacity of the CDS system has been proven in lab and field testing.

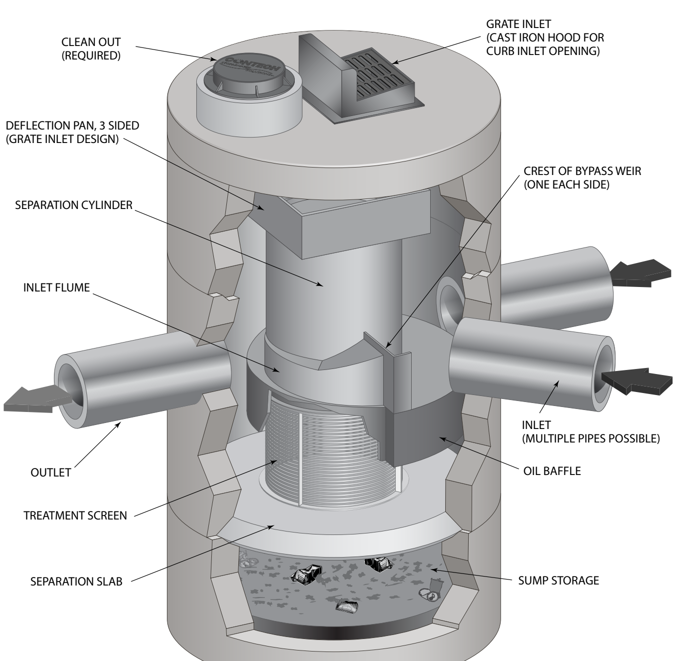
Operation Overview

Stormwater enters the diversion chamber where the diversion weir guides the flow into the unit's separation chamber and pollutants are removed from the flow. All flows up to the system's treatment design capacity enter the separation chamber and are treated.

Swirl concentration and screen deflection force floatables and solids to the center of the separation chamber where 100% of floatables and neutrally buoyant debris larger than the screen apertures are trapped.

Stormwater then moves through the separation screen, under the oil baffle and exits the system. The separation screen remains clog free due to continuous deflection.

During the flow events exceeding the treatment design capacity, the diversion weir bypasses excessive flows around the separation chamber, so captured pollutants are retained in the separation cylinder.



Design Basics

There are three primary methods of sizing a CDS system. The Water Quality Flow Rate Method determines which model size provides the desired removal efficiency at a given flow rate for a defined particle size. The Rational Rainfall Method™ or the and Probabilistic Method is used when a specific removal efficiency of the net annual sediment load is required.

Typically in the Unites States, CDS systems are designed to achieve an 80% annual solids load reduction based on lab generated performance curves for a gradation with an average particle size (d50) of 125 microns (μm). For some regulatory environments, CDS systems can also be designed to achieve an 80% annual solids load reduction based on an average particle size (d50) of 75 microns (μm) or 50 microns (μm).

Water Quality Flow Rate Method

In some cases, regulations require that a specific treatment rate, often referred to as the water quality design flow (WQQ), be treated. This WQQ represents the peak flow rate from either an event with a specific recurrence interval, e.g. the six-month storm, or a water quality depth, e.g. 1/2-inch (13 mm) of rainfall.

The CDS is designed to treat all flows up to the WQQ. At influent rates higher than the WQQ, the diversion weir will direct most flow exceeding the WQQ around the separation chamber. This allows removal efficiency to remain relatively constant in the separation chamber and eliminates the risk of washout during bypass flows regardless of influent flow rates.

Treatment flow rates are defined as the rate at which the CDS will remove a specific gradation of sediment at a specific removal efficiency. Therefore the treatment flow rate is variable, based on the gradation and removal efficiency specified by the design engineer.

Rational Rainfall Method™

Differences in local climate, topography and scale make every site hydraulically unique. It is important to take these factors into consideration when estimating the long-term performance of any stormwater treatment system. The Rational Rainfall Method combines site-specific information with laboratory generated performance data, and local historical precipitation records to estimate removal efficiencies as accurately as possible.

Short duration rain gauge records from across the United States and Canada were analyzed to determine the percent of the total annual rainfall that fell at a range of intensities. US stations' depths were totaled every 15 minutes, or hourly, and recorded in 0.01-inch increments. Depths were recorded hourly with 1-mm resolution at Canadian stations. One trend was consistent at all sites; the vast majority of precipitation fell at low intensities and high intensity storms contributed relatively little to the total annual depth.

These intensities, along with the total drainage area and runoff coefficient for each specific site, are translated into flow rates using the Rational Rainfall Method. Since most sites are relatively small and highly impervious, the Rational Rainfall Method is appropriate. Based on the runoff flow rates calculated for each intensity, operating rates within a proposed CDS system are determined. Performance efficiency curve determined from full scale laboratory tests on defined sediment PSDs is applied to calculate solids removal efficiency. The relative removal efficiency at each operating rate is added to produce a net annual pollutant removal efficiency estimate.

Probabilistic Rational Method

The Probabilistic Rational Method is a sizing program Contech developed to estimate a net annual sediment load reduction for a particular CDS model based on site size, site runoff coefficient, regional rainfall intensity distribution, and anticipated pollutant characteristics.

The Probabilistic Method is an extension of the Rational Method used to estimate peak discharge rates generated by storm events of varying statistical return frequencies (e.g. 2-year storm event). Under the Rational Method, an adjustment factor is used to adjust the runoff coefficient estimated for the 10-year event, correlating a known hydrologic parameter with the target storm event. The rainfall intensities vary depending on the return frequency of the storm event under consideration. In general, these two frequency dependent parameters (rainfall intensity and runoff coefficient) increase as the return frequency increases while the drainage area remains constant.

These intensities, along with the total drainage area and runoff coefficient for each specific site, are translated into flow rates using the Rational Method. Since most sites are relatively small and highly impervious, the Rational Method is appropriate. Based on the runoff flow rates calculated for each intensity, operating rates within a proposed CDS are determined. Performance efficiency curve on defined sediment PSDs is applied to calculate solids removal efficiency. The relative removal efficiency at each operating rate is added to produce a net annual pollutant removal efficiency estimate.

Treatment Flow Rate

The inlet throat area is sized to ensure that the WQQ passes through the separation chamber at a water surface elevation equal to the crest of the diversion weir. The diversion weir bypasses excessive flows around the separation chamber, thus preventing re-suspension or re-entrainment of previously captured particles.

Hydraulic Capacity

The hydraulic capacity of a CDS system is determined by the length and height of the diversion weir and by the maximum allowable head in the system. Typical configurations allow hydraulic capacities of up to ten times the treatment flow rate. The crest of the diversion weir may be lowered and the inlet throat may be widened to increase the capacity of the system at a given water surface elevation. The unit is designed to meet project specific hydraulic requirements.

Performance

Full-Scale Laboratory Test Results

A full-scale CDS system (Model CDS2020-5B) was tested at the facility of University of Florida, Gainesville, FL. This CDS unit was evaluated under controlled laboratory conditions of influent flow rate and addition of sediment.

Two different gradations of silica sand material (UF Sediment & OK-110) were used in the CDS performance evaluation. The particle size distributions (PSDs) of the test materials were analyzed using standard method "Gradation ASTM D-422 "Standard Test Method for Particle-Size Analysis of Soils" by a certified laboratory.

UF Sediment is a mixture of three different products produced by the U.S. Silica Company: "Sil-Co-Sil 106", "#1 DRY" and "20/40 Oil Frac". Particle size distribution analysis shows that the UF Sediment has a very fine gradation (d50 = 20 to 30 μm) covering a wide size range (Coefficient of Uniformity, C averaged at 10.6). In comparison with the hypothetical TSS gradation specified in the NJDEP (New Jersey Department of Environmental Protection) and NJCAT (New Jersey Corporation for Advanced Technology) protocol for lab testing, the UF Sediment covers a similar range of particle size but with a finer d50 (d50 for NJDEP is approximately 50 μm) (NJDEP, 2003).

The OK-110 silica sand is a commercial product of U.S. Silica Sand. The particle size distribution analysis of this material, also included in Figure 1, shows that 99.9% of the OK-110 sand is finer than 250 microns, with a mean particle size (d50) of 106 microns. The PSDs for the test material are shown in Figure 1.

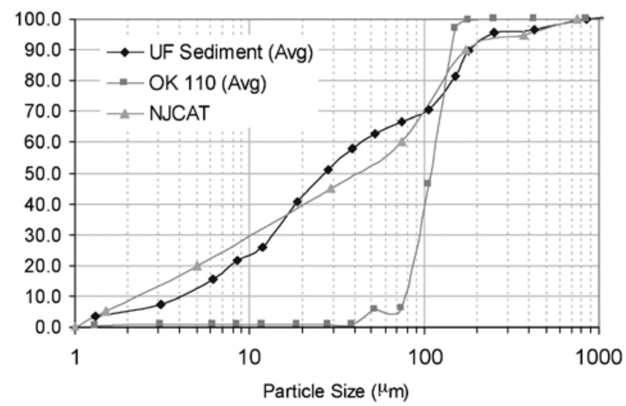


Figure 1. Particle size distributions

Tests were conducted to quantify the performance of a specific CDS unit (1.1 cfs (31.3-L/s) design capacity) at various flow rates, ranging from 1% up to 125% of the treatment design capacity of the unit, using the 2400 micron screen. All tests were conducted with controlled influent concentrations of approximately 200 mg/L. Effluent samples were taken at equal time intervals across the entire duration of each test run. These samples were then processed with a Dekaport Cone sample splitter to obtain representative sub-samples for Suspended Sediment Concentration (SSC) testing using ASTM D3977-97 "Standard Test Methods for Determining Sediment Concentration in Water Samples", and particle size distribution analysis.

Results and Modeling

Based on the data from the University of Florida, a performance model was developed for the CDS system. A regression analysis was used to develop a fitting curve representative of the scattered data points at various design flow rates. This model, which demonstrated good agreement with the laboratory data, can then be used to predict CDS system performance with respect to SSC removal for any particle size gradation, assuming the particles are inorganic sandy-silt. Figure 2 shows CDS predictive performance for two typical particle size gradations (NJCAT gradation and OK-110 sand) as a function of operating rate.

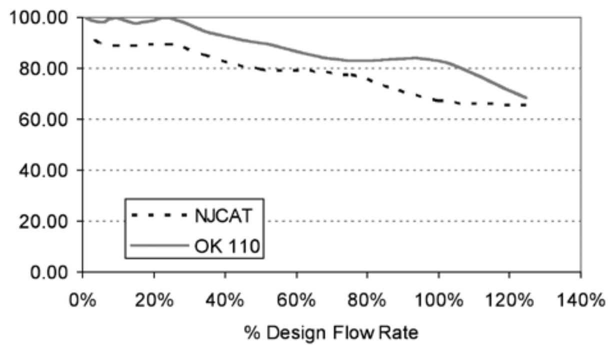


Figure 2. CDS stormwater treatment predictive performance for various particle gradations as a function of operating rate.

Many regulatory jurisdictions set a performance standard for hydrodynamic devices by stating that the devices shall be capable of achieving an 80% removal efficiency for particles having a mean particle size (d50) of 125 microns (e.g. Washington State Department of Ecology — WASDOE - 2008). The model can be used to calculate the expected performance of such a PSD (shown in Figure 3). The model indicates (Figure 4) that the CDS system with 2400 micron screen achieves approximately 80% removal at the design (100%) flow rate, for this particle size distribution (d50 = 125 μm).

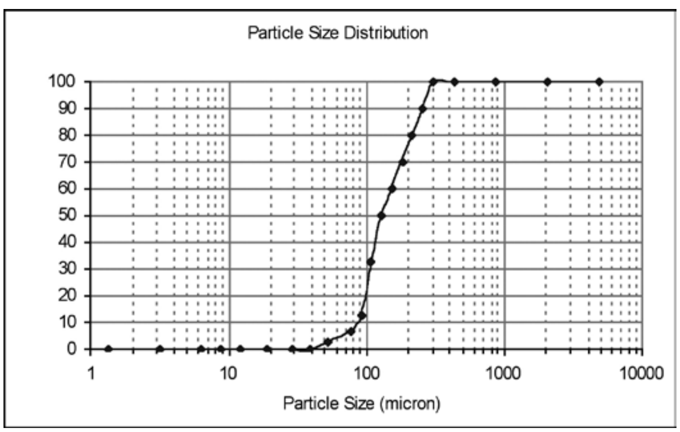


Figure 3. WASDOE PSD

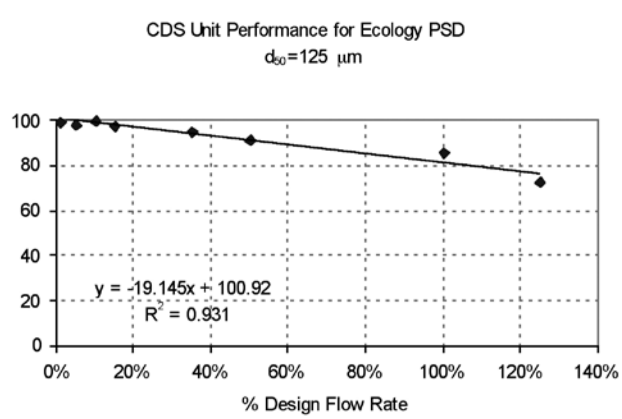


Figure 4. Modeled performance for WASDOE PSD.

Maintenance

The CDS system should be inspected at regular intervals and maintained when necessary to ensure optimum performance. The rate at which the system collects pollutants will depend more heavily on site activities than the size of the unit. For example, unstable soils or heavy winter sanding will cause the grit chamber to fill more quickly but regular sweeping of paved surfaces will slow accumulation.

Inspection

Inspection is the key to effective maintenance and is easily performed. Pollutant transport and deposition may vary from year to year and regular inspections will help ensure that the system is cleaned out at the appropriate time. At a minimum, inspections should be performed twice per year (e.g. spring and fall) however more frequent inspections may be necessary in climates where winter sanding operations may lead to rapid accumulations, or in equipment washdown areas. Installations should also be inspected more frequently where excessive amounts of trash are expected.

The visual inspection should ascertain that the system components are in working order and that there are no blockages or obstructions in the inlet and separation screen. The inspection should also quantify the accumulation of hydrocarbons, trash, and sediment in the system. Measuring pollutant accumulation can be done with a calibrated dipstick, tape measure or other measuring instrument. If absorbent material is used for enhanced removal of hydrocarbons, the level of discoloration of the sorbent material should also be identified

during inspection. It is useful and often required as part of an operating permit to keep a record of each inspection. A simple form for doing so is provided.

Access to the CDS unit is typically achieved through two manhole access covers. One opening allows for inspection and cleanout of the separation chamber (cylinder and screen) and isolated sump. The other allows for inspection and cleanout of sediment captured and retained outside the screen. For deep units, a single manhole access point would allows both sump cleanout and access outside the screen.

The CDS system should be cleaned when the level of sediment has reached 75% of capacity in the isolated sump or when an appreciable level of hydrocarbons and trash has accumulated. If absorbent material is used, it should be replaced when significant discoloration has occurred. Performance will not be impacted until 100% of the sump capacity is exceeded however it is recommended that the system be cleaned prior to that for easier removal of sediment. The level of sediment is easily determined by measuring from finished grade down to the top of the sediment pile. To avoid underestimating the level of sediment in the chamber, the measuring device must be lowered to the top of the sediment pile carefully. Particles at the top of the pile typically offer less resistance to the end of the rod than consolidated particles toward the bottom of the pile. Once this measurement is recorded, it should be compared to the as-built drawing for the unit to determine weather the height of the sediment pile off the bottom of the sump floor exceeds 75% of the total height of isolated sump.

Cleaning

Cleaning of a CDS systems should be done during dry weather conditions when no flow is entering the system. The use of a vacuum truck is generally the most effective and convenient method of removing pollutants from the system. Simply remove the manhole covers and insert the vacuum hose into the sump. The system should be completely drained down and the sump fully evacuated of sediment. The area outside the screen should also be cleaned out if pollutant build-up exists in this area.

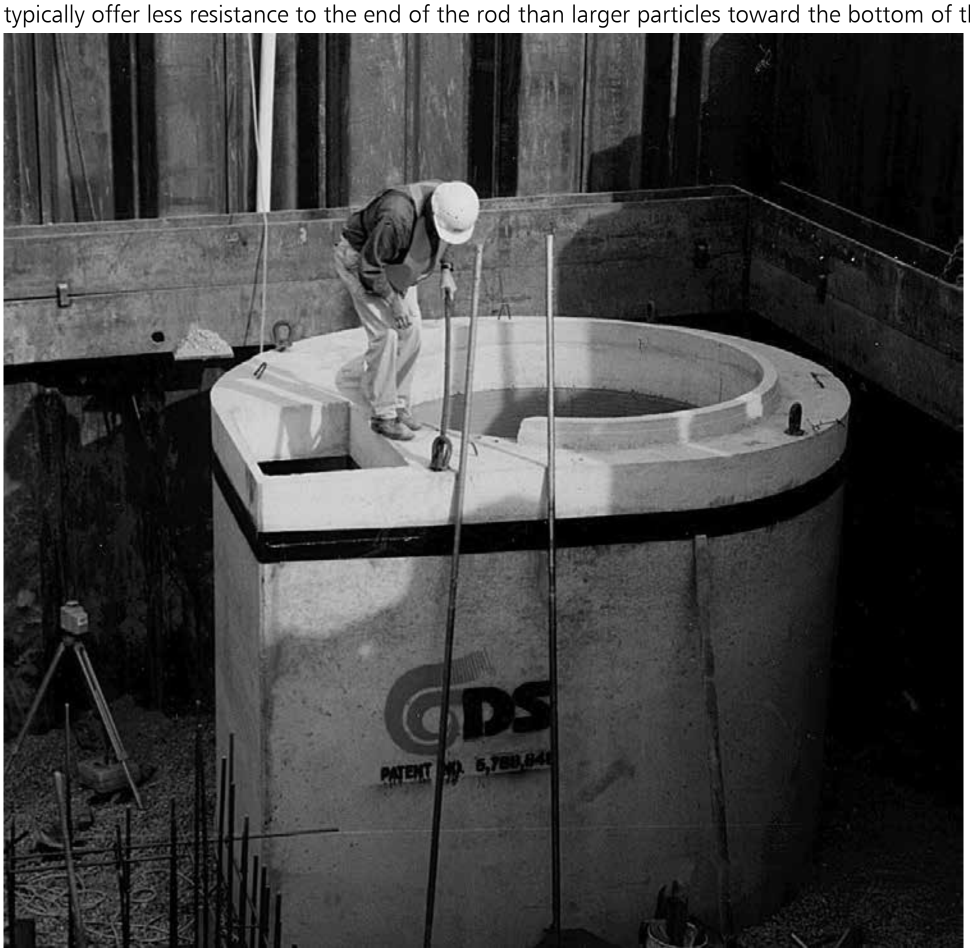
In installations where the risk of petroleum spills is small, liquid contaminants may not accumulate as quickly as sediment. However, the system should be cleaned out immediately in the event of an oil or gasoline spill. Motor oil and other hydrocarbons that accumulate on a more routine basis should be removed when an appreciable layer has been captured. To remove these pollutants, it may be preferable to use absorbent pads since they are usually less expensive to dispose than the oil/water emulsion that may be created by vacuuming the oily layer. Trash and debris can be netted out to separate it from the other pollutants. The screen should be cleaned to ensure it is free of trash and debris.

Manhole covers should be securely seated following cleaning activities to prevent leakage of runoff into the system from above and also to ensure that proper safety precautions have been followed. Confined space entry procedures need to be followed if physical access is required. Disposal of all material removed from the CDS system should be done in accordance with local regulations. In many jurisdictions, disposal of the sediments may be handled in the same manner as the disposal of sediments removed from catch basins or deep sump manholes. Check your local regulations for specific requirements on disposal.

CDS Model	Diameter		Distance from Water Surface to Top of Sediment Pile		Sediment Storage Capacity	
	ft	m	ft	m	y^3	m^3
CDS1515	3	0.9	3.0	0.9	0.5	0.4
CDS2015	4	1.2	3.0	0.9	0.9	0.7
CDS2015	5	1.5	3.0	0.9	1.3	1.0
CDS2020	5	1.5	3.5	1.1	1.3	1.0
CDS2025	5	1.5	4.0	1.2	1.3	1.0
CDS3020	6	1.8	4.0	1.2	2.1	1.6
CDS3025	6	1.8	4.0	1.2	2.1	1.6
CDS3030	6	1.8	4.6	1.4	2.1	1.6
CDS3035	6	1.8	5.0	1.5	2.1	1.6
CDS4030	8	2.4	4.6	1.4	5.6	4.3
CDS4040	8	2.4	5.7	1.7	5.6	4.3
CDS4045	8	2.4	6.2	1.9	5.6	4.3
CDS5640	10	3.0	6.3	1.9	8.7	6.7
CDS5653	10	3.0	7.7	2.3	8.7	6.7
CDS5668	10	3.0	9.3	2.8	8.7	6.7
CDS5678	10	3.0	10.3	3.1	8.7	6.7

Table 1: CDS Maintenance Indicators and Sediment Storage Capacities

Note: To avoid underestimating the volume of sediment in the chamber, carefully lower the measuring device to the top of the sediment pile. Finer silty particles at the top of the pile may be more difficult to feel with a measuring stick. These finer particles typically offer less resistance to the end of the rod than larger particles toward the bottom of the pile.



CDS Inspection & Maintenance Log

CDS Model: ______________________ Location: ______________________

Date	Water depth to sediment[1]	Floatable Layer Thickness[2]	Describe Maintenance Performed	Maintenance Personnel	Comments

1. The water depth to sediment is determined by taking two measurements with a stadia rod: one measurement from the manhole opening to the top of the sediment pile and the other from the manhole opening to the water surface. If the difference between these measurements is less than the values listed in table 1 the system should be cleaned out. **Note: to avoid underestimating the volume of sediment in the chamber, the measuring device must be carefully lowered to the top of the sediment pile**.
2. For optimum performance, the system should be cleaned out when the floating hydrocarbon layer accumulates to an appreciable thickness. In the event of an oil spill, the system should be cleaned immediately.

SUPPORT
- Drawings and specifications are available at www.ContechES.com.
- Site-specific design support is available from our engineers.

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The product(s) described may be protected by one or more of the following US patents: 5,322,629; 5,624,576; 5,707,527; 5,759,415; 5,788,848; 5,985,157; 6,027,639; 6,350,374; 6,406,218; 6,641,720; 6,511,595; 6,649,048; 6,991,114; 6,998,038; 7,186,058; 7,296,692; 7,297,266; related foreign patents or other patents pending.

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