Appendix A
Questionnaires

All questionnaires received by DNREC as part of this study are available digitally on the "Oak Orchard Coastal Drainage Engineering Evaluation Digital Data" CD included with this report.

Bay Beach Drainage and Flooding Concerns
Delaware Department of Natural Resources and Environmental Control

Introduction

The Delaware Department of Natural Resources and Environmental Control (DNREC) requests assistance from property owners and renters in Bay Beach Communities to identify locations within the community where drainage or flooding issues regularly occur. The information collected will be used to identify areas of concern. Areas of concern will be evaluated on site by engineers under contract with DNREC. It may be necessary for the engineers to contact you for additional information.

Part I: Contact Information

Name: ______________________ Date: ______________________

Community Name: ______________________ Phone: ______________________

Property Address: ______________________ Email: ______________________

Ownership Information ☐ Full-Time Resident ☐Part-Time Resident ☐Rental Property

Part II: Drainage Observations

Please complete the following sections for each drainage issue observed.

For this section, include descriptions of drainage issues related to the following: ponding water, water coming out of inlets, water not able to drain through inlet or pipe, or flooding of roadway or driveway due to slow moving (or not moving at all) water.

Description of concern:

____

____

Location of drainage concern (please be as specific as possible):

____

____

Probable cause of drainage concern (for example: poor drainage system, low lying area)

____

____

When does this drainage concern typically occur (for example: during high tides, during northeast winds, after every rain event, after large rain events, sometimes after a rain event, during hurricanes or significant coastal events)

____

____

How often does this drainage concern occur (for example: once a month, twice a year, only during hurricanes. Also, list approximate date of the last time the drainage concern occurred)

____

____

Please use additional sheets, if necessary.

Bay Beach Drainage and Flooding Concerns
Delaware Department of Natural Resources and Environmental Control

Part III: Flooding Observations

Please complete the following sections for each flooding issue you observed.
For this section, include descriptions of flooding issues related to the following: flooding of a building or structure, property flooding, or yard flooding.)

Description of flooding concern:

Location of flooding concern (please be as specific as possible):

Probable cause of flooding (for example: undersized pipe, building elevation too low, low lying area)

When does this flooding concern typically occur (for example: during high tides, during northeast winds, after every rain event, after large rain events, sometimes after a rain event, during hurricanes or significant coastal events)

How often does this flooding concern occur (for example: once a month, twice a year, only during hurricanes. Also, list approximate date of the last time the problem occurred)

Part IV – Other Observations

Please provide additional information regarding drainage or flooding in your community that may be beneficial for this study.

Return Survey via mail or email to:

Stephen G. Wright
DNREC Division of Watershed Stewardship
89 Kings Highway
Dover, Delaware 19901
Stephen.Wright@state.de.us

Please use additional sheets, if necessary.

Appendix B

Community Maps with Location of Drainage Concerns and Proposed Solutions

Table B.1: Questionnaire Identification Numbers and Corresponding Local Addresses

ID	*Address*
101	105 Comanche Cir.
102	29222 Honeysuckle Knoll
103	28136 Layton Davis Rd.
104	31346 River Rd.
105	31304 River Rd.
106	31450 River Rd.
201	32026 River Rd.
202	32032 River Rd.
203	32046 River Rd.
204	32066 River Rd.
205	30030 Wheatley Ln.
206	32100 River Rd.
207	32116 River Rd.
208	32172 River Rd.
209	32193 River Rd.
210	32197 River Rd.
211	32197 River Rd.
212	32280 River Rd.
213	32306 River Rd.
214	32363 River Rd.
215	32368 River Rd.
216	32381 River Rd.
217	28510 Nanticoke Ave.
218	32442 River Rd.
219	32560 River Rd.
220	28535 Cerise Ln.
221	32598 River Rd.
222	32702 Oak Orchard Rd.
223	28449 Delaware Ave.
224	28332 Elizabeth St.
225	33220 Mercer Ave.
226	33238 Mercer Ave.
227	33254 Mercer Ave.
228	33283 Mercer Ave.
229	28300 Russell Rd.
230	28258 Basin Rd.
231	28256 Cannon St.
301	28362 Roberta Ln.
302	33048 Circle Dr.

ID	*Address*
303	33002 Circle Dr.
304	32966 Circle Dr.
305	35503 Irvin Way
306	28452 Boyce Rd.
307	32284 Oak Orchard Rd.
308	32548 W James Ct.
309	32560 E James Ct.
310	32510 W Fairfax Ct.
311	32529 E. Fairfax Ct.
312	32541 E Fairfax Ct.
313	32552 E Fairfax Ct.
314	32405 W Penn Ct.
315	27818 Crown Ct.
316	32535 Captains Way
317	32545 Captains Way
401	27740 Oak Meadows Dr.
402	27730 Oak Meadow Dr.
403	27680 Oak Meadow Dr.
404	27632 Oak Meadow Dr.
405	27624 Oak Meadow Dr.
406	27606 Oak Meadow Dr.
407	27592 Clover Ln.
408	27547 Briar Ln.
409	27525 Clover Ln.
410	27522 Oak Meadow Dr.
411	27465 Oak Meadow Dr.
412	27843 Oak Meadow Dr.
413	31913 Schooner Dr.
414	27223 Clipper Dr.
415	27239 Carvel Dr.
416	27208 Carvel Dr.
417	30772 Mount Joy Rd.
501	31 Hosier St. (Selbyville, DE)
502	34305 S Harbor Dr.
503	35254 7th St.
504	214 Pear St.

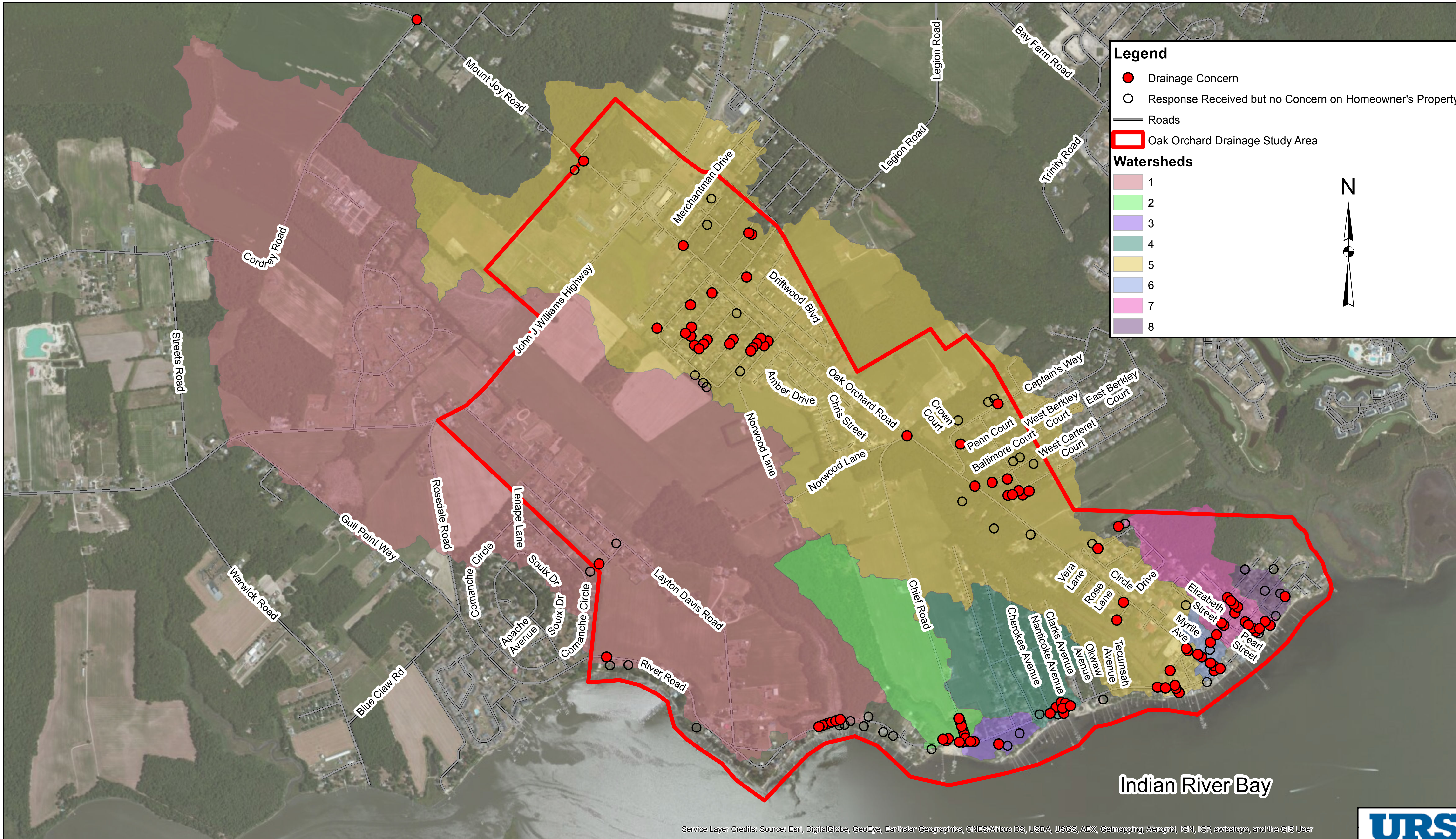

Figure B.1: Oak Orchard Study Area

0 0.25 0.5 1 Miles

Figure B.2: Oak Orchard (West) Location of Drainage Concerns

Figure B.3: Oak Orchard (East) Location of Drainage Concerns

Appendix C

Drainage Recommendation and Prioritization Tables

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership[2]*	*Agency*
OO_01	102	29222 Honeysuckle Knoll	Localized runoff	The ditch in front of 29222 Honeysuckle Knoll floods 2 to 3 times a year.	Improve ditch, create infiltration zone	Increase the size of the existing ditch west of Honeysuckle Knoll, and extend to the 90° bend in the road. Install culvert under Honeysuckle Knoll to existing low area. Create a well-defined infiltration area.	This solution has the potential to decrease the frequency and duration of flooding from localized runoff.	Primarily public ownership (road), although one drainage easement through private property would be required.	DNREC
OO_02	104.1	Road in front of 31346 River Rd.	Localized runoff	Road in front of 31346 River Rd. floods during heavy rain (yearly).	Regrade road shoulder, replace storm drain pipe cap	Mill existing road shoulder to provide positive drainage to the existing catch basin. Replace the existing 4-inch perforated PVC end cap (Barguard by Agri drain or similar) to maximize discharge.	This solution has the potential to decrease the frequency and duration of flooding from localized runoff.	Primarily public ownership (road), although a portion of the roadway shoulder may be on private property.	DNREC
OO_04A	201.1, 202.1, 203.1, 205.1, 207.1, 501.4	River Rd., approximately 2,000 feet west of Chief Rd.	Localized runoff and tidal flooding	A low area in River Rd. floods several times a year. An existing culvert that crosses River Rd. at this location is currently covered by collapsed concrete. Water was observed flowing upstream from Indian River Bay.	Upgrade storm drain, raise road	Raise approximately 400 feet of River Rd. from elevation 2 feet NAVD88 to a finished elevation of 3 to 4 feet NAVD88 (an increase of 1 to 2 feet) from 32026 River Rd. to 31362 River Road. Install ditch north of River Rd. if needed that connects to existing ditch system. Replace existing pipe, and install backflow prevention on the bay side of the pipe. A tide gate may be required if the marsh north of River Rd. is a salt water marsh to provide saltwater flow to maintain environmental functions.	This solution has the potential to decrease the frequency and duration of flooding from localized runoff and bay tidal events.	Primarily public ownership (road), although an easement through private property would be required to replace the storm drain pipe.	DelDOT
OO_04B	201.1, 202.1, 203.1, 205.1, 207.1, 501.4	River Rd., approximately 2,000 feet west of Chief Rd.	Localized runoff and tidal flooding	A low area in River Rd. floods several times a year. An existing culvert that crosses River Rd. at this location is currently covered by collapsed concrete. Water was observed flowing upstream from Indian River Bay.	Upgrade storm drain, install bulkhead	Install approximately 400 feet of bulkhead north of River Rd. from the existing culvert to an elevation of 4 feet NAVD88, and regrade road to provide positive drainage toward the marsh. Install ditch north of River Rd., if needed, that connects to existing ditch system. Replace existing pipe, and install backflow prevention on the bay side of the pipe. A tide gate may be required if the marsh north of River Rd. is a saltwater marsh to provide saltwater flow to maintain environmental functions.	Environmental permitting would be required to construct a bulkhead in the marsh. This solution has the potential to decrease the frequency and duration of flooding from localized runoff and bay tidal events.	5 to 10 easements through private property would be required.	DNREC - High Priority
OO_06	203.2, 205.2, 206.1, 207.2, 208.1, 209, 209.1, 210, 210.1, 211, 211.1, 213.1, 218.1, 406.1	Intersection of Chief Rd. and River Rd.	Localized runoff and tidal flooding	River Rd. and nearby properties flood frequently (flooding observed during 2 days of field work). The existing storm drain pipe could not be identified during field investigation.	Raise road, extend bulkhead, and upgrade storm drain	Raise approximately 500 feet of River Rd. from elevation 2 feet NAVD88 to a finished elevation of 4 feet NAVD88 (an increase of 1 to 2 feet) from 400 feet west of the intersection of River Rd. and Chief Rd., to 100 feet east of the intersection. Install approximately 300 feet of bulkhead to tie existing bulkhead south of existing parking lot to elevation of 4 feet NAVD88. Regrade boat ramp to keep it from flooding the parking lot. Possibly resize and replace existing storm drain pipe with backflow prevention on the bay side of pipe. A tide gate may be required if the marsh north of River Rd. is a saltwater marsh to provide saltwater flow to maintain environmental functions.	This solution has the potential to decrease the frequency and duration of flooding from localized runoff and bay tidal events.	Primarily public ownership (road), although two easements through private property would be required.	DelDOT
OO_07	212.1	Property to the right of 32280 River Rd.	Tidal flooding	There is a tidal ponding area adjacent to the property of 32280 River Rd. that often holds water. No flooding outside of pond has been observed.	Regrade private yard	Raise yard to keep water from the tidal ponding area from impacting the property.	Environmental permitting would be required to grade near the tidal wetland. This solution has the potential to decrease the frequency and duration of flooding from bay tidal events.	Entirely private ownership.	Homeowner Implementation/ Technical Assistance

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership[2]*	*Agency*
OO_08	214.1, 214.2, 215.1, 215.2, 216, 216.1, 217, 501.6	Intersection of River Rd. with Nanticoke Ave. and Cherokee Ave.	Localized runoff and tidal flooding	River Rd. and nearby properties flood 4 to 8 times per year. Existing catch basins contained standing water and large debris (e.g., a horseshoe crab). There is a gap between the existing bulkheads on the bayside of River Rd., which allows tidal water to drain toward River Rd. There is a boat ramp at this site. Several driveways and Nanticoke Avenue are at the same elevation as the roadway.	Install bulkhead, install backflow prevention	Install approximately 200 feet of bulkhead to tie existing bulkhead to elevation 2 feet NAVD88 on the Indian River Water Sport Club property. Regrade boat ramp to tie in to bulkhead elevation. Install backflow prevention on bayside of storm drain pipe.	This solution has the potential to decrease the frequency and duration of flooding from bay tidal events.	Construction would be entirely private property.	DNREC
OO_09A	207.3, 213.2, 219, 220, 220.1, 501.5	Intersection of Cerise Ave. and River Rd., and Roberta Ln.	Localized runoff and tidal flooding	There is flooding by the existing drainage ditch that typically occurs during abnormally high tides (monthly) and drains slowly. Flooding due to localized runoff has also been observed. The existing culvert is a 30-inch pipe that was submerged during the field investigation (plans provided by DNREC indicate that the material is either PVC or RCP). Roadway flooding was observed during the field investigation. Flooding extends to Roberta Ln. several times a year.	Raise road, upgrade existing storm drain	Raise approximately 600 feet of River Rd. from elevation 2 feet NAVD88 to a finished elevation of 3 feet NAVD88 (an increase of 6 inches to 1 foot). Resize the existing 30-inch storm drain pipe and provide backflow prevention on the bayside of the pipe. A tide gate may be required if the marsh north of River Rd. is a saltwater marsh to provide saltwater flow to maintain environmental functions.	This solution has the potential to decrease the frequency and duration of flooding from localized runoff and bay tidal events.	An easement through private property would be required to replace the existing storm drain pipe. An existing fence would need to be removed and replaced.	DelDOT
OO_09B	207.3, 213.2, 219, 220, 220.1, 501.5	Intersection of Cerise Ave. and River Rd., and Roberta Ln.	Localized Runoff and Tidal Flooding	There is flooding by the existing drainage ditch that typically occurs during abnormally high tides (monthly) and drains slowly. Flooding due to localized runoff has also been observed. The existing culvert is a 30-inch pipe that was submerged during the field investigation (plans provided by DNREC indicate that the material is either PVC or RCP). Roadway flooding was observed during the field investigation. Flooding extends to Roberta Ln. several times a year.	Levee/bulkhead	Install bulkhead on either side of the existing ditch to provide additional storage for water and to prevent flooding of roadway and nearby properties. Resize the existing 30-inch storm drain pipe and provide backflow prevention on the bayside of the pipe. A tide gate may be required if the marsh north of River Rd. is a saltwater marsh to allow enough saltwater flow to maintain environmental functions.	This solution has the potential to decrease the frequency and duration of flooding from localized runoff and bay tidal events. Construction would occur in the existing marsh.	5 to 10 easements through private property would be required. An existing fence would need to be removed and replaced.	DNREC - High Priority
OO_10	222, 220.2	Intersection of Cerise Ave. and Oak Orchard Rd.	Localized runoff	Cerise Ln. floods several times a year as a result of localized runoff. Runoff from Oak Orchard Rd. drains onto Cerise Ave., exceeding the capacity of the existing storm drain system. Several of the observed catch basins are full of debris and standing water.	Upgrade existing storm drain	Clean all existing catch basins, and resize existing storm drain pipes as necessary. Add tide gate to existing outfall located at the existing tidal pond West of Cerise Ave.	This solution has the potential to reduce the frequency and duration of flooding. Flooding from the tidal pond would not be impacted by this proposed solution.	Construction would be entirely on a single private property within the mobile home park.	DNREC
OO_11	207.4, 219.1, 221.1, 223.1, 501.2	Intersection of Oak Orchard Rd. and River Rd.	Localized runoff and tidal flooding	The intersection of Oak Orchard Rd. and River Rd. floods monthly as a result of backwater from the bay flowing through the existing storm drain system that is exacerbated by local runoff.	NA, DelDOT has a proposed design.	DelDOT is planning to replace the existing storm drain and to add a tide gate at the intersection of Oak Orchard Rd. and River Rd.	NA	NA	DelDOT

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership[2]*	*Agency*
OO_12	223.2, 223.3, 223.4, 223.5, 223.6, 224.1, 225.1, 226, 226.1, 226.2, 227.1, 227.2, 228.1, 229.1, 501.7	Delaware St. & Mercer Ave	Localized runoff and tidal flooding	The roadside ditches and catch basins on Mercer Ave. and Delaware St. are receiving coastal water during high tide, but cannot drain during low tide. The existing outlet pipe is covered by sediment during high tide (observed covered by sediment during the field investigation) and only drains when the sand is cleared by local residents. The ditches and catch basins were observed to have 1 to 2 feet of standing water during the field investigation.	Clean existing ditch, upgrade storm drain	Clean existing ditch along Mercer Ave. and Delaware St. and replace existing storm drain system. Extend pipe into the bay and install backflow prevention. A sediment transport study would be required to verify the extent of the deposition zone and length of pipe required. Install dock over the proposed pipe to provide maintenance access.	This solution has the potential to decrease the frequency and duration of flooding from localized runoff and bay tidal events.	Primarily public ownership (road), although an easement through a single private property would be required to replace the pipe that extends to the bay.	DNREC - High Priority
OO_13	230.1, 231.1, 231.2, 501.8	Forest Dr.	Localized runoff	Forest Dr. floods several times a year. Water was observed ponding at a localized low area at the intersection of Delaware St. and Forest Ave. during the field investigation.	Install storm drain	Install catch basin at the center of the west bound lane of Forest Ave. 10 feet from the intersection with Delaware St. and route to the existing roadside ditch on the east side of Mercer Ave.	This solution has the potential to reduce the frequency and duration of flooding. The proposed storm drain would need to cross water and sewer lines.	Public ownership (road).	DNREC - High Priority
OO_16	302.1	Northwest corner of Circle Dr.	Localized runoff	Circle Dr. floods following large rain events. An existing catch basin with a 12-inch corrugated metal pipe may not be adequate for the existing drainage area. The pipe connects to the Vera Ln. stormwater system before releasing to the existing ditch system.	Upgrade existing storm drain	Replace approximately 700 feet of storm drain pipe from Circle Dr. down Vera Ln. to the existing outfall.	This solution has the potential to reduce the frequency and duration of flooding at Circle Dr. from localized runoff. The proposed storm drain would need to cross water and sewer lines.	Public ownership (road) and private ownership. Two to seven easements through private property would be required.	DNREC
OO_18	307.1, 308, 308.1, 308.2, 309, 309.1, 310, 310.1,	W. Fairfax Ct. and W. James Ct. (southwest corner of Captains Grant), and Oak Orchard Rd. west of Captains Grant	Localized runoff	Water collects at the western end of W. Fairfax Ct. and W. James Ct. as a result of the lack of an outlet toward Oak Orchard Rd. causing flooding several times a year. Clogging of existing 3:1 V-ditches and 12-inch CMP and PVC culverts on both W. Fairfax Ct. and W. James Ct. from sediment and debris was observed in the field. Oak Orchard Rd. also floods near this location as a result of the lack of conveyance system.	Install ditch, implement sediment control	Install ditch east of Oak Orchard Rd. from approximately 200 feet southwest of W. James Court to existing 24-inch CMP culvert that crosses Captains Way and flows to the existing wet pond. Install ditch from W. Fairfax Ct. and W. James Ct. to proposed Oak Orchard Rd. ditch. Remove sediment and debris from the existing storm drain pipe that crosses Oak Orchard Rd. and from around the grate inlets. Resize stormdrain pipe if necessary. Install 6- to 12-inch risers over the existing grate inlets or install sediment basins to reduce sedimentation at the storm drain.	This solution has the potential to reduce the frequency and duration of flooding at Fairfax Ct. and W. James Ct., and Oak Orchard Rd. from localized runoff. The sewer line in the western lane of Oak Orchard Rd. should not impact the proposed design. Several existing trees south of W. James Ct. and W. Fairfax Ct. may impact the proposed ditch system.	Public (road) and private ownership. Private ownership is primarily homeowner association, with one to two additional easements through private property required.	DNREC - High Priority
OO_19	314	32405 W Penn Ct.	Localized runoff	The driveway of 32405 W. Penn Ct. floods during large rain events. A sag in the driveway is at approximately the same elevation of the V-ditch on either side. The elevation of the driveway increases rapidly toward the homeowner's garage.	Regrade private driveway	Raise private driveway to provide positive drainage toward road, and install a driveway entrance culvert to hydraulically connect the ditch north of the driveway to the ditch to the south.	This solution has the potential to reduce the frequency and duration of flooding of the driveway.	Primarily private ownership (driveway), although some construction would be in the road right-of-way.	Homeowner Implementation/ Technical Assistance
OO_20	317.1	Swale in front of 32545 Captains Way	Localized runoff	The ditch in front of 32545 Captains Way floods several times a year, impacting the roadway and driveways. The existing culverts are up to 80% full of sediment, and the ditch appears to be at the same level as the driveway.	Raise driveway, replace existing storm drain	Raise driveway (north and south sections) of 32545 Captains Way, and replace existing culverts at a higher elevation with enough of a slope to avoid sedimentation. Clear the existing ditches as needed to provide positive conveyance toward the southwest.	This solution has the potential to reduce the frequency and duration of flooding.	Primarily private ownership (driveway), although some construction would be in the road right-of-way.	Homeowner Implementation/ Technical Assistance
OO_21	501.3	Intersection of Norwood Ln. and Oak Orchard Rd.	Localized runoff	Flooding at the intersection of Norwood Ln., Chief Rd., and Oak Orchard Rd. is due to localized runoff. The existing dry pond discharges to a poorly defined ditch south of Chief Rd. that flows south to the primary Oak Orchard Rd. ditch where it combines with runoff from Oak Meadows downstream of a 12-inch concrete culvert.	Install/upgrade ditch, upgrade existing storm drain	Install/regrade ditch on both sided of Chief Rd. from the intersection with Norwood Dr. (storm drain pipe from dry pond) to the existing storm drain 200 feet to the southwest on Chief Road. Resize the existing 12-inch concrete pipe that directs flow from Oak Meadows to the existing ditch system.	This solution has the potential to reduce the frequency and duration of flooding. An existing sewer line under the northbound lane of Chief Rd. may extend to the existing ditch.	Primarily public ownership (road), although a portion of the roadway shoulder may be on private property.	DNREC

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership[2]*	*Agency*
OO_22	401, 401.1, 401.2, 401.3, 402, 402.1, 403.1, 404.1, 404.2, 404.3, 404.4, 407, 407.1, 408, 408.1	Oak Meadow Dr. adjacent to Norwood Ln. (southeast corner of Oak Meadows)	Localized runoff	The southeastern corner of Oak Meadow Dr. floods several times a year. Thistle Ln., Clover Ln., and Briar Ln. also flood near existing catch basins. The existing storm drain system comprises 12- to 18-inch pipes, catch basins, and roadside ditches. Several of the inlet pipes are at lower elevations than outlet pipes and it appears the system is head driven.	Install/upgrade ditch, upgrade existing storm drain	Resize and replace existing storm drain pipes, and replace with a gravity driven storm drain system. Pipes should be replaced from Briar Ln. to the outlet into the Amber Drive wet pond. Install/upgrade ditches as needed, including from the driveway of 27706 Oak Meadows Dr. to the existing catch basin.	Resizing the existing storm drain system and upgrading it to a gravity driven system has the potential to reduce the frequency and duration of nuisance flooding.	Public (road) and private ownership. Easements through five to 10 properties would be required.	DNREC - High Priority
OO_27	411	27465 Oak Meadow Dr.	Localized runoff	The yard and driveway of 27465 Oak Meadows Dr. flood monthly. The driveway and yard are a local low point.	Install rain garden, raise private driveway	Install a rain garden or biofiltration to create a controlled local low point with infiltration capacity. Raise existing driveway to the maximum extent possible based on the garage elevation (approximately 6 inches) to provide positive conveyance to roadway and proposed rain garden.	This solution has the potential to reduce the frequency and duration of flooding.	Private ownership.	Homeowner Implementation/ Technical Assistance
OO_28	412	27843 Oak Meadow Dr.	Localized runoff	The driveway, yard, and roadway of 27843 Oak Meadows Dr. floods monthly. There is no drainage at this location, so water ponds and infiltrates slowly.	Install ditch	Install a ditch north of Briar Ln. from the intersection of Oak Meadow Dr. and Briar Ln. to the existing catch basin. Install storm drain pipes under driveways as needed.	This solution has the potential to reduce the frequency and duration of flooding.	Public ownership (road).	DNREC - High Priority
OO_29	413	31913 Schooner Dr.	Localized runoff	The driveway and yard of 31913 Schooner Dr. flood several times a year. The existing storm drain pipe under the driveway is covered by tall grass at the inlet and leaves at the outlet. A storm drain pipe from the existing ditch to a stormwater management facility south of the property also has debris and vegetation blocking flow.	Maintenance	Remove debris impeding flow into existing storm drain pipe and ditches as needed to convey runoff to the existing stormwater management facility.	This solution has the potential to reduce the frequency and duration of flooding.	Private ownership (River Village homeowners association).	Homeowner Association/ Technical Assistance
OO_30	414, 414.1	27223 Clipper Dr. and road in front of property	Localized runoff	The driveway and yard of 27223 Clipper Dr. flood several times a year. There does not appear to be an engineered drainage solution at this property (there may have been a ditch that has filled in over time).	Install ditch	Install ditch east of Clipper Dr. from 27223 Clipper Dr. around corner past the driveway of 27237 Clipper Dr. to connect with the existing ditch. Install a storm drain pipe under the driveway of 27237 Clipper Dr. or a valley gutter.	This solution has the potential to reduce the frequency and duration of flooding. There is a light post and electric box east of Clipper Dr. that could impact construction. Sewer lines are located within the roadway and would not be expected to impact construction.	Private ownership. Primarily River Village homeowners association, although an additional easement through private property may be required.	Homeowner Association/ Technical Assistance
OO_31	None (DNREC noted concern from community meeting)	Driftwood Stormwater Management facility to Caravel Dr.	Localized runoff	Oak Orchard Rd. floods from the Driftwood Stormwater Management facility to Caravel Dr. as a result of the lack of conveyance system.	Install storm drain, retrofit stormwater management ponds	Install approximately 700 feet of closed storm drain with catch basins as needed northwest of Oak Orchard Rd. from the existing stormwater management facility southeast of Schooner Dr. to 300 feet south of Caravel Drive. Connect proposed storm drain system to the existing stormwater management facility and retrofit as needed to store additional flow. Install approximately 1,200 feet of closed storm drain with catch basins as needed northwest of Oak Orchard Rd. from the existing stormwater management facility south of Driftwood Blvd. to 400 feet south of Schooner Dr. Connect proposed storm drain system to the existing stormwater management facility and retrofit as needed to store additional flow.	This solution has the potential to reduce the frequency and duration of flooding. Sewer and water lines along Oak Orchard Rd. may be impacted.	Primarily public ownership (road), with two easements through homeowner association property required.	DNREC
OO_32	416.1	Intersection of Caravel Dr. and Oak Orchard Rd.	Localized runoff	The intersection of Caravel Dr. and Oak Orchard Rd. flood several times a year. Currently, water ponds in the grass area (which resembles a ditch) on the corner of Caravel Dr. and Oak Orchard Rd. and infiltrates.	Improve existing ditch	Improve the existing ditch so runoff flows from Caravel Dr. to the existing stormwater management facility to the north.	This solution has the potential to reduce the frequency and duration of flooding. Sewer and water lines along Oak Orchard Rd. should not be impacted by the proposed design.	Primarily public ownership (road), although an easement will be required to work on the existing stormwater management facility (homeowner association).	DNREC

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership[2]*	*Agency*
OO_33	417.1	Road in front of 30772 Mount Joy Rd.	Localized runoff	The right of way along Mounty Joy Rd. floods in front of 30772 Mount Joy Rd. several times a year. The flooding does not impact the road.	Regrade private lot	Regrade private lot to provide positive drainage to roadway.	This solution has the potential to reduce the frequency and duration of flooding. Sewer lines on the northbound lane of Mount Joy Rd. should not be impacted.	Private property.	Homeowner Implementation/ Technical Assistance
OO_34	410, S_22, S_21, S_10, S_09	Commercial property north of Route 24 / Route 5 intersection	Localized runoff	There is flooding at 27522 Oak Meadow Dr. and the commercial property north of the intersection of Route 24 and Oak Orchard Road. The runoff appears to be generated north of Route 24. Currently, there is no storage or conveyance for this runoff as it travels through the Oak Meadows neighborhood, Chief Rd. ditch / storm drain, and the existing ditch parallel to Oak Meadows Rd. to the existing 30-inch storm drain pipe to the Indian River Bay.	Implement regional stormwater management facility	Implement a regional stormwater management facility (such as a dry pond) in the vacant lot between Route 24 and Oak Meadow Dr. to retain upland waters. Design facility to include storage for potential future development of the vacant lot. Install storm drain system and ditches as needed to capture runoff from Mount Joy Rd. and Route 24 (and potentially Caravel Dr.).	This solution has the potential to reduce the frequency of flooding for the Oak Meadows neighborhood, Chief Rd., and River Rd. near the Cerise Ave. intersection. The lot is primarily composed of grasses, but some wetland vegetation may be present. Sewer lines run parallel to Route 24 south of the road and should not impact the proposed design.	Private ownership (undeveloped lot owned by a single property owner).	DNREC
OO_35	303	33002 Circle Dr.	Localized runoff	The yard and the basement of 33002 Circle Dr. flood because the house is at a local low point.	Regrade private lot	Raise property to allow positive drainage to road.	This solution has the potential to reduce the frequency and duration of flooding. The mobile home is sitting on a frame so raising the lot may be cost prohibitive.	Private ownership.	Homeowner Implementation/ Technical Assistance
OO_36	223.3	Intersection of Myrtle Ave. and Delaware St.	Localized runoff	There is a relative low point at the intersection of Myrtle Ave. and Delaware St. where water ponds frequently. Ponding water was observed in the field.	Install valley gutter	Install valley gutter at the intersection of Myrtle Ave. and Delaware St. parallel to Delaware St. from the northern roadway fillet curve of Myrtle Ave. to the southern roadway fillet curve.	This solution has the potential to reduce the frequency and duration of flooding. The proposed valley gutter would cross sewer and water lines, but neither should be impacted by the design.	Public ownership (road).	DNREC
OO_37	223.2	Delaware St. and Oak Orchard Rd.	Localized runoff	There is a relative low point at the intersection of Delaware St. and Oak Orchard Rd. where water ponds frequently. Ponding water was observed in the field.	Install valley gutter	Install valley gutter at the intersection of Oak Orchard Rd. and Delaware St. parallel to Oak Orchard Rd. from the northern roadway fillet curve of Delaware St. to the southern roadway fillet curve.	This solution has the potential to reduce the frequency and duration of flooding at the intersection. Flooding may still occur on the roadway shoulder south of the intersection. The proposed valley gutter would cross sewer and water lines, but neither should be impacted by the design.	Public ownership (road).	DNREC
OO_38	None (DNREC noted concern from community meeting)	River View Ave.	Tidal flooding	The existing stormdrain system on the west side of River View Ave. drains to the Indian River Bay. The stormdrain pipe extends into the bay. The existing catch basin closest to Mercer Ave. is substantially lower than the local grade and is partially covered by sediment and debris.	Upgrade existing storm drain	Remove and replace the catch basin closest to Mercer Ave. and reconnect to existing stormdrain pipe. Install backflow prevention on the bay side of the pipe extending into the Indian River Bay and replace the pipe if leaks are present.	This solution has the potential to reduce the frequency and duration of flooding on the street. There are water and sewer lines in the vicinity of the existing storm drain system.	Entirely private ownership (private road).	DNREC

NAVD88 = North American Vertical Datum of 1988
PVC = polyvinyl chloride
RCP = reinforced concrete pipe
DNREC = Delaware Department of Natural Resources and Environmental Control
DelDOT = Delaware Department of Transportation
NA = Not applicable
CMP = corrugated metal pipe

[1] For location of questionnaire concerns see Figure B.2: Oak Orchard (West) Location of Drainage Concerns and Figure B.3: Oak Orchard (East) Location of Drainage Concerns

[2] Property ownership was based on Sussex County GIS parcel data, this information will need to be verified and/or updated prior to full design

Table C.2: Proposed Solution Prioritization Matrix

Solution ID	Number of Questionnaire Observations (0-12)	Ingress and Egress (0-12)	Frequency of Drainage/ Flooding (0-12)	Flooding Severity (0-12)	Complexity of Solution (0-8)	Easement/ Right of Way Requirement (0-8)	Environmental Impact of Proposed Solution (0-6)	Permitting (0-6)	Agricultural Impact (0-8)	Septic System Impact (0-8)	Project Cost (0-8)	Maintenance Cost (0-8)	Total (0-108)
OO_01	0	3[2]	8	8	8	4	6	6	8	8	8	0	67
OO_02	0	3[2]	6	8	4	8	6	6	8	8	8	4	69
OO_04A	6	6[2]	8	12	0	4	6	6	8	8	0	4	68
OO_04B[1]	6	6[2]	8	12	0	0	0	0	8	8	0	4	52
OO_06	12	12	10	12	0	4	6	6	8	8	0	4	82
OO_07	Homeowner solution (not ranked)												
OO_08	6	6[2]	10	12	4	0	3	0	8	8	4	4	65
OO_09A	6	12	10	12	0	0	6	6	8	8	0	4	72
OO_09B[1]	6	12	10	12	0	0	0	0	8	8	0	4	60
OO_10	0	3[2]	8	8	8	0	6	6	8	8	4	4	63
OO_11	Delaware Department of Transportation is planning to upgrade (not ranked)												
OO_12[1]	6	12	10	12	4	4	6	6	8	8	0	4	80
OO_13[1]	0	6	10	8	4	8	6	6	8	8	4	8	76
OO_16	0	3[2]	8	8	0	4	6	6	8	8	0	4	55
OO_18[1]	0	12	8	8	8	4	6	6	8	8	4	4	76
OO_19	Homeowner solution (not ranked)												
OO_20	Homeowner solution (not ranked)												
OO_21	0	3[2]	8	8	4	8	6	6	8	8	4	4	67
OO_22[1]	6	12	8	12	4	0	6	6	8	8	0	4	74
OO_27	Homeowner solution (not ranked)												
OO_28[1]	0	3[2]	10	4	8	8	6	6	8	8	8	4	73
OO_29	0	6	8	4	8	0	6	6	8	8	8	4	66
OO_30	0	0	8	4	8	0	6	6	8	8	8	4	60
OO_31	0	6	6	8	0	4	6	6	8	8	0	4	56
OO_32	0	3[2]	8	8	8	4	6	6	8	8	8	4	71
OO_33	Homeowner solution (not ranked)												
OO_34	12	6[2]	10	12	0	0	3	0	8	8	0	4	63
OO_35	Homeowner solution (not ranked)												
OO_36	0	0	8	8	8	8	6	6	8	8	4	8	72
OO_37	0	3[2]	8	8	8	8	6	6	8	8	4	8	75
OO_38	0	6	8	8	4	0	6	3	8	8	4	4	59

[1] Proposed solution selected by DNREC for conceptual design
[2] There are two access roads so the "Ingress and Egress" score is multiplied by 0.5

Appendix D

Field Reconnaissance Photographs

URS Corporation (URS) performed a detailed field reconnaissance of the Oak Orchard community in September of 2014. The primary goal of the site visit was to inspect the location of drainage concerns described in the questionnaires completed by the residents of the community. Photographs were taken as part of the field reconnaissance to record the existing conditions.

During the field reconnaissance URS identified the type of flooding, the extent of each problem, current conditions, and impacts on the surrounding areas at each identified drainage concern. URS also assessed potential site constraints, access issues, utility conflicts, and site ownership to determine the feasibility of proposed drainage improvements.

Photographs were taken at the location of each drainage concern, and a representative selection of these photographs is available in Figure D.1 to Figure D.39. A brief description of the drainage concern at each photograph is provided, as well as the proposed solution ID the photograph is associated with. The solutions were labeled using the two-letter identifier "OO" followed by a two-digit number. The two-letter identifier is used for consistency with the Bay Beach Drainage Study nomenclature. A summary of the drainage problems, potential solutions, possible constraints, and expected effectiveness, are supplied for each solution in Appendix C.

Figure D.1: Standing water in front of 29222 Honeysuckle Knoll (OO_01)

Figure D.2: Road in front of 31346 River Road with standing water (OO_02)

Figure D.3: River Road approximately 2,000 feet west of Chief Road (OO_04)

Figure D.4: Culvert with collapsed headwall crossing River Road approximately 2,000 feet west of Chief Road (OO_04)

Figure D.5: The intersection of River Road and Chief Road flooded during an abnormally high tide (OO_06)

Figure D.6: Marsh near the intersection of River Road and Chief Road flooded during an abnormally high tide (OO_06)

Figure D.7: Tidal pond near 32280 River Road (OO_07)

Figure D.8: Flooded area south of the intersection of Nanticoke Avenue and River Road (OO_08)

Figure D.9: River Road near the intersection of Cerise Avenue with standing water (OO_09)

Figure D.10: Surcharging catch basin at River Road near the intersection of Cerise Avenue (OO_09)

Figure D.11: Existing catch basin full of debris at Cerise Avenue (OO_10)

Figure D.12: The intersection of Oak Orchard Road and River Road with standing water (OO_11)

Figure D.13: Mercer Avenue ditch with standing water (OO_12)

Figure D.14: Catch basin adjacent to Mercer Avenue full of standing water (OO_12)

Figure D.15: Mercer Avenue culvert completely covered by sediment (OO_12)

Figure D.16: Intersection of Delaware Avenue and Forest Drive with standing water (OO_13)

Figure D.17: Existing catch basin at Circle Drive cul-de-sac (OO_16)

Figure D.18: Existing catch basin full of debris west of Captains Grant wet pond (OO_18)

Figure D.19: Shoulder of Oak Orchard Road southwest of Captains Way (OO_17)

Figure D.20: Poorly defined ditch west of Fairfax Court (OO_18)

Figure D.21: Driveway of 32405 West Penn Court with a sag at approximately the same elevation as the v-ditch upstream and downstream (OO_19)

Figure D.22: Ditch and culvert through 32545 Captains Way driveway full of sediment (OO_20)

Figure D.23: The intersection of Oak Orchard Road and Chief Road/Norwood Lane (OO_22)

Figure D.24: Culvert crossing Chief Road partially filled with sediment (OO_22)

Figure D.25: Existing catch basin south of Oak Meadows Drive (OO_22)

Figure D.26: Yard of 27465 Oak Meadow Drive (OO_27)

Figure D.27: Ponding/infiltration area near 27843 Oak Meadows Drive (OO_28)

Figure D.28: 31913 Schooner Drive culvert full of leaf litter (OO_29)

Figure D.29: Schooner Drive Dry Pond inlet pipe partially covered by vegetation and leaf litter (OO_29)

Figure D.30: Yard of 27223 Clipper Drive (OO_30)

Figure D.31: Oak Orchard Road between Caravel Drive and Driftwood Village (OO_31)

Figure D.32: Existing ditch at the corner of Oak Orchard Road and Caravel Drive (OO_32)

Figure D.33: Roadway shoulder in front of 30772 Mount Joy Road (OO_33)

Figure D.34: Open space between Oak Meadow Drive and John J Williams Highway (OO_34)

Figure D.35: Yard and residential structure of 33002 Circle Drive (OO_35)

Figure D.36: Intersection of Myrtle Avenue and Delaware Street (OO_36)

Figure D.37: Intersection of Oak Orchard Road and Delaware Street (OO_37)

Figure D.38: Catch basin partially filled with debris at River View Avenue (OO_38)

Figure D.39: Pipe extending out to the Indian River Bay from River View Avenue (OO_38)

Appendix E
Field Data Forms

All field data forms completed by URS during the field investigation in September 2014 as part of this study are available digitally on the "Oak Orchard Coastal Drainage Engineering Evaluation Digital Data" CD included with this report.

Oak Orchard – Coastal Drainage Engineering Study
Field Data Form

DATE/TIME____________________ **INITIALS** ______________________________
SITE NUMBERs_____________________ **PHOTO IDs** ____________________________

1. SITE DESCRIPTION

Name: ____
Address: ____

Site Ownership

☐ State/Federal ☐ Private ☐ Unknown ☐ Other__________________

---

2. OBSERVED PROBLEM

Brief description (from questionnaire)____
____

Type of Flooding

☐ Roadway Flooding ☐ Property Flooding (e.g., yard) ☐ Coastal Flooding

Cause of problem *(field observation)*

☐ Ponded water on lot ☐ Debris/Trash/Obstruction ☐ Dune

☐ Ponded water on road ☐ Backup water from marsh/canal ☐ Elevation/ relief

☐ Sedimentation ☐ Ditch Issue ☐ Other_________

---

3. DESIGN CONSTRAINTS

Potential conflicts with existing utilities

☐ Sewer ☐ Water ☐ Gas ☐ Cable ☐ Electric ☐ Power Line ☐ Others:__________

Potential permitting factors

☐ Dam Safety ☐ Impact to Wetlands ☐ Impact to Streams
☐ Floodplain Fill ☐ Impact to Specimen Trees ☐ Impact to Wildlife Refuge

Approximate existing channel geometry (*if applicable****):***

Dimensions:______________________ Slope:______________________________
Roughness Description:____

---

4. PROPOSED SOLUTION

Solution type

☐ Ditch Maintenance ☐ Create/Improve Ditch ☐ Enlarge Wetland Area

☐ Re-grade ☐ Improve Roadway ☐ Modify Existing Structure

☐ Resize/Remove Culvert ☐ Rain Garden ☐ Replenish Dune

☐ Install Culvert/ SD Pipe ☐ Install Tide Gate ☐ Other: _____________

Oak Orchard – Coastal Drainage Engineering Study
Field Data Form

Solution Category

☐ Engineering Solution ☐ Maintenance Solution ☐ Homeowner Solution

Drainage area to proposed solution

Drainage Area: ____ (ac) Impervious Area: ____ (ac)

Type: ____________________

Describe the proposed Solution:____

____

____

____

____

Sketch existing condition (red) and proposed solution (blue) *(note key existing features, drainage patterns, construction/maintenance access, conflicts with existing utilities, etc.)*

Appendix F
Hydrologic Analysis

INTRODUCTION

URS Corporation (URS) performed a hydrologic analysis as part of the Delaware Department of Natural Resources and Environmental Control (DNREC) Oak Orchard Coastal Drainage Engineering Evaluation. The results of the hydrologic modeling will be used for the conceptual design of proposed solutions and to assist DNREC with further assessment of management strategies for improving drainage in the Oak Orchard community.

The hydrologic model for the Oak Orchard Drainage Study was developed using HEC-HMS 4.0 (USACE, 2010). Data used for modeling included current Geographic Information System (GIS) datasets and precipitation data from the Delaware Department of Transportation (DelDOT) Drainage and Stormwater Manual (2008). Eight watersheds were studied in this analysis with a total drainage area of 3.1 square miles. The model was calibrated using a nearby stream gage and was validated using the U.S. Geological Survey (USGS) regression equations.

WATERSHED DATA

The data sets used in the hydrologic modeling are described in the sections below.

Topography

The National Elevation Dataset (NED) 1/9-arc second (3-meter) raster from the USGS was used to delineate the Oak Orchard watersheds. The vertical datum for the topographic data is the North American Vertical Datum of 1988 (NAVD 88). The elevation raster was modified based on existing drainage systems, and the GIS automated basin creation tools were used to create the watersheds and sub-basins.

Soil Data

The Natural Resources Conservation Service (NCRS) soil survey geographic database (NRCS, 2009) was used to obtain GIS soil data coverage for modeling the contributing watersheds.

Land Use Data

Land use data from the 2007 Delaware Office of Management and Budget Delaware Land Use/Land Cover was used to represent existing land-use conditions. The 2011 National Land Cover Database (NLCD) dataset was also considered; however, the 2007 Land Use/Land Cover dataset is specific to Delaware and has nearly twice as many unique categories as the 2011 NLCD dataset. The orthographic satellite imagery from 2011 was used to verify that there were no major changes in land use between 2007 and 2011.

Curve Number

Rainfall infiltration losses were estimated using the Runoff Curve Number (RCN), which is a function of land use and soil type. There are 32 land use/land cover types in the Oak Orchard study area. RCN values were estimated for each land use using the NRCS *Urban Hydrology for Small Watersheds TR-55* (TR-55) methodology (NRCS, 1986), satellite imagery, and parcel data. Each of these categories has a different RCN value depending on the hydrologic soil group classification of the land, shown in Table F-1.

Table F-1: Land-Use/Land Cover and Corresponding RCN Values

2007 Land-Use/Land Cover		Soil Type/ RCN			
ID	Description	A	B	C	D
111	Single-Family Dwellings	54	70	80	85
112	Multi-Family Dwelling	77	85	90	92
114	Mobile Home Parks/Courts	57	72	81	86
120	Commercial	89	92	94	95
121	Retail Sales/Wholesale/Professional Services	89	92	94	95
150	Utilities	30	58	71	78
160	Mixed Urban or Built-up Land	89	92	94	95
180	Institutional/Governmental	81	88	91	93
190	Recreational	39	61	74	80
211	Cropland	66	76	82	85
213	Idle Fields	68	79	86	89
230	Confined Feeding Operations/Feedlots/Holding	68	79	86	89
240	Farmsteads and Farm Related Buildings	59	74	82	86
310	Herbaceous Rangeland	49	69	79	84
320	Shrub/Brush Rangeland	30	48	65	73
330	Mixed Rangeland	49	69	79	84
410	Deciduous Forest	30	55	70	77
420	Evergreen Forest	30	55	70	77
430	Mixed Forest	30	55	70	77
440	Clear-cut	45	66	77	83
520	Natural Lakes and Ponds	100	100	100	100
530	Man-made Reservoirs and Impoundments	100	100	100	100
540	Bays and Coves	100	100	100	100
560	Non-tidal Open Water	100	100	100	100
610	Non-tidal Forested Wetland	57	73	82	86
622	Non-tidal Scrub/Shrub Wetland	48	67	77	83
623	Non-tidal Emergent Wetland	68	79	86	89
672	Tidal Scrub/Shrub Wetland	48	67	77	83
673	Tidal Emergent Wetland	68	79	86	89
750	Extraction (bare earth)	77	86	91	94
760	Transitional (incl. cleared, filled, and graded)	30	58	71	78
770	Tidal Shoreline	77	86	91	94

HYDROLOGIC MODEL

URS developed the hydrologic model using HEC-HMS 4.0 (USACE, 2010). URS developed the elevation preprocessing, watershed delineation, and attribute management using ArcGIS 10.1 (ESRI, 2012). Figure F-1 displays the 8 watersheds and 31 sub-basins included in the hydrologic analysis. Figure F-2 display the 31 sub-basins, 24 junctions, 8 outfalls, and the routing reaches modeled using HEC-HMS. The sub-basins were selected based on the locations of existing drainage concerns and hydrologic considerations.

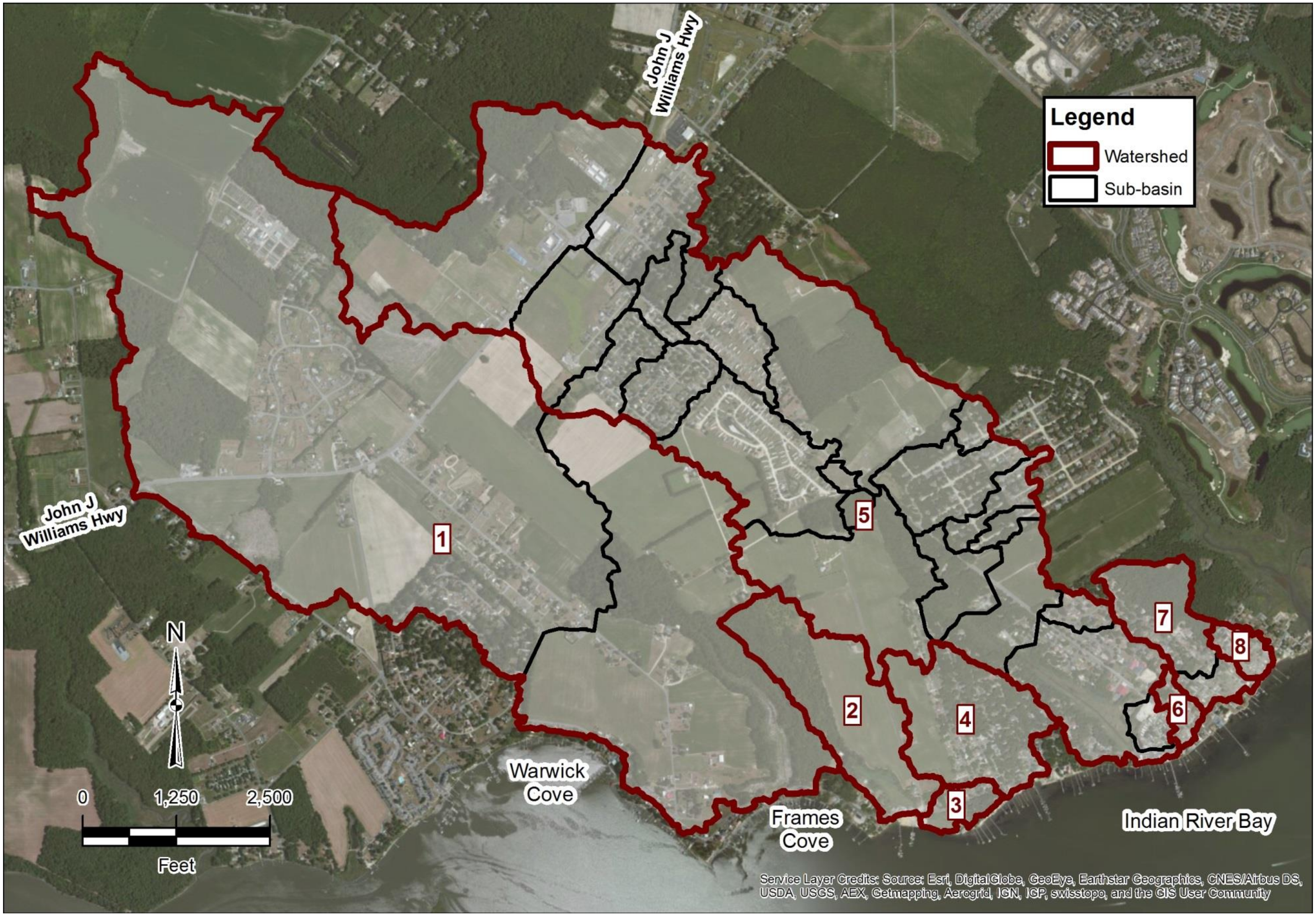

Figure F-1: Oak Orchard Drainage Divide Map

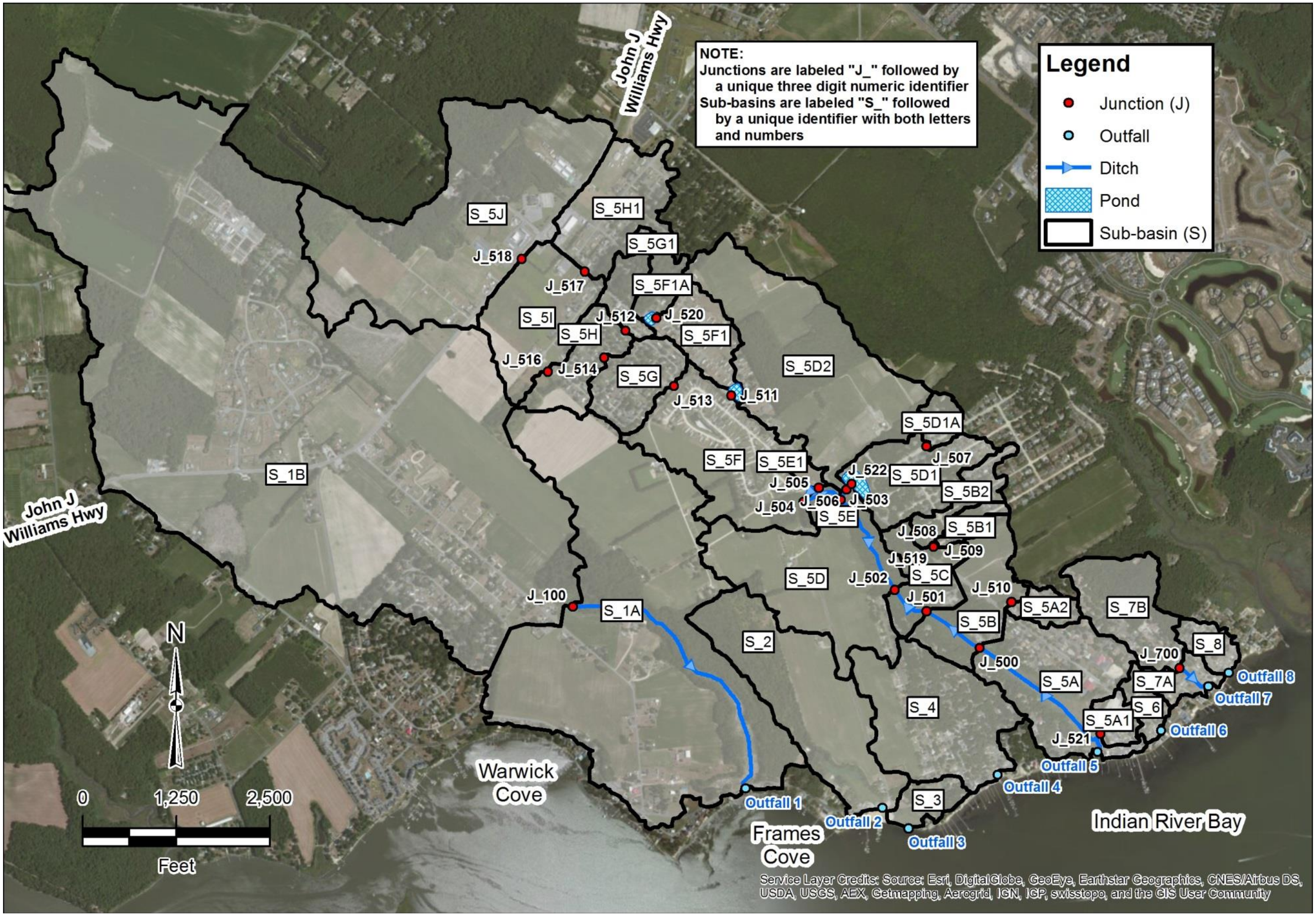

Figure F-2: Oak Orchard Hydrologic Analysis Map

WATERSHED PARAMETERS

HEC-HMS is a flexible modeling software with several options to model rainfall-runoff attributes. The modeling components were selected based on requests from DNREC and the existing site conditions. To model the hydrology, URS used TR-55 methodology to calculate RCNs and thereby estimate infiltration. We used the Soil Conservation Service (SCS) unit hydrograph (NRCS, 1986) to route sub-basin runoff based on lag time and a 24-hour SCS rainfall distribution. The SCS rainfall distribution is considered to be a conservative estimate for rainfall.

Key hydrologic parameters required for the HEC-HMS methodology selected include watershed-related parameters and precipitation data associated with design storms. Watershed-related input parameters included the RCN, drainage area size, and rain-runoff time of concentration.

Runoff Curve Number

Rainfall infiltration losses were estimated using the RCN, wherein RCN is the parameter used to represent the properties of soil type and land use. RCN values were derived for each sub-basin in the study area; the relationships among soil type, land use, and RCN value are given in Table F-2. The study area has primarily Hydrologic Group A soils. Composite RCN values were calculated using ArcGIS 10.1 (ESRI, 2012).

Table F-2: Hydrologic Parameters for Sub-basins

Basin Name	Area (mi^2)	Runoff Curve Number	Time of Concentration (minutes)	Lag Time (minutes)
S_1A	0.43	58	134	80
S_1B	1.10	61	391	235
S_2	0.12	47	129	78
S_3	0.02	53	33	20
S_4	0.11	54	84	50
S_5A	0.09	59	53	32
S_5A1	0.01	56	26	16
S_5A2	0.01	49	25	15
S_5B	0.05	56	53	32
S_5B1	0.01	49	24	14
S_5B2	0.02	49	36	22
S_5C	0.03	51	69	41
S_5D	0.12	61	81	49
S_5D1	0.06	49	48	29
S_5D1A	0.01	47	34	21
S_5D2	0.17	58	155	93
S_5E	0.01	48	25	15

Basin Name	Area (mi^2)	Runoff Curve Number	Time of Concentration (minutes)	Lag Time (minutes)
S_5E1	0.005	64	18	11
S_5F	0.11	67	39	24
S_5F1	0.03	53	56	34
S_5F1A	0.02	49	60	36
S_5G	0.04	65	39	23
S_5G1	0.02	57	62	37
S_5H	0.03	67	53	32
S_5H1	0.07	57	78	47
S_5I	0.07	63	84	50
S_5J	0.25	50	166	100
S_6	0.01	52	41	25
S_7A	0.01	49	74	44
S_7B	0.05	38	81	49
S_8	0.01	48	55	33

Drainage Area Size

The watershed sub-basins shown in Figure F-1 and Figure F-2 were delineated, and the enclosed areas were calculated using the existing elevation data in ArcGIS 10.1. The sub-basin parameters summarized in Table F-2 were then input into the HEC-HMS model for the hydrologic simulation.

Sub-basin Time of Concentration

Time of concentration (T_c) is defined as the time it takes for stormwater runoff to travel from the most hydraulically distant point of the watershed to a point of interest within the watershed. T_c values for each sub-basin were determined using the T_c estimation method described in NRCS TR-55 (1986). Runoff from each sub-basin was divided into a sheet flow segment (non-concentrated runoff from the most distant point), shallow concentrated flow segment, channel flow, and storm drain flow.

T_c values for sheet and shallow concentrated flows were estimated using generalized curves that relate surface and channel conditions, slope, and flow velocity. A maximum sheet flow segment length of 100 feet was used, as this is conservative and in accordance with NRCS recommendations. Shallow concentrated flow lengths were assumed to extend from the end of the sheet flow portion of runoff to the origin of a well-defined channel segment.

Velocities for channel flows were calculated using Manning's equation and "bankfull" discharges. Hydraulic roughness characteristics were based on aerial imagery and field reconnaissance.

The calculated travel time (T_t) values for sheet flow, shallow concentrated flow, and channel flow were summed to give the total T_c value for each sub-basin. The estimated T_c values for the sub-basin are summarized in Table F-2. The lag time is calculated by multiplying the time of concentration by 0.6 (NRCS, 2010).

Time of Concentration between Basins

Several of the sub-basins were created where there was either no conveyance downstream or inadequate conveyance. In these situations, shallow concentrated flow travel times were computed to account for the lag time from one junction to the next. The lag time between basins is calculated by multiplying the time of concentration by 0.6 (NRCS, 2010). The estimated travel times between sub-basins are summarized in Table F-3.

Table F-3: Travel time between sub-basins

Upstream Junction	Downstream Junction	Travel Time (minutes)	Lag Time (minutes)
J_510	J_500	6	4
J_513	J_505	44	26
J_514	J_513	41	25
J_518	J_516	39	24
J_517	J_516	46	28
J_512	J_514	9	5
J_520	J_511	39	23
J_511	J_504	43	26
J_507	J_506	18	11
J_509	J_501	13	8
J_516	J_514	90	54

Pond Storage

Three ponds were considered in the hydrologic analyses: the pond northwest of the Captains Grant neighborhood, the pond southeast of Driftwood Village, and the pond southeast of Schooner Drive. Design plans for these ponds were not available; therefore, the storage was calculated using the NED elevation data and aerial imagery.

Precipitation Data

Precipitation data used as input in HEC-HMS are from DelDOT Road Design Manual, which is slightly more conservative than rainfall intensities from NOAA's Atlas 14 Precipitation Data. The rainfall depths for the 2-, 10-, 25-, 50-, and 100-year rainfall events were used to calculate the discharges at the 50-, 10-, 4-, 2-, and 1-percent-annual-chance events, respectively. The 24-hour depth values from DelDOT drainage manual and NOAA are shown in Table F-4. The Type II SCS 24-hour rainfall distribution is a widely accepted conservative estimate for precipitation.

Table F-4: 24-Hour Duration Rainfall Depths

Return Period	24-Hour-Depth, inches	
	DelDOT Drainage Manual*	NOAA Atlas 14**
2-year	3.4	3.39
10-year	5.3	5.28
25-year	6.7	6.62
50-year	7.9	7.8
100-year	9.2	9.12

*= Depth specified for Sussex County in the Delaware Department of Transportation (DelDOT) Drainage Manual
**= Depth specified at Oak Orchard by the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Precipitation Data

CALIBRATION AND VALIDATION

USGS gage 1484695 at Beaverdam Ditch is approximately 6 miles from the Oak Orchard study area, and has a drainage area of 2.2 square miles. The 2-, 10-, 25-, 50-, and 100-year peak flows were calculated for Beaverdam Ditch using flood frequency analysis. The flood frequency analysis was performed using PeakFQ.

The DelDOT design storm requirements for roads in Delaware are based on the road's functional classification and the type of drainage feature (e.g., stormdrain, ditch, or culvert). Based on the DelDOT drainage manual, the design storms for most drainage features in Oak Orchard are likely to be the 10- and 25-year event. Therefore, these storm events were used for calibration. Watersheds 1 and 5 (1.53 square miles and 1.25 square miles, respectively) are closest in size to the Beaverdam Ditch drainage area (2.2 square miles), so the 10- and 25-year flows for these two watersheds were used for calibration. The area of both ungaged watersheds is within 50 percent of the area of the gaged watershed (i.e., between 1.1 and 3.3 acres). This is within the range the USGS recommends when using a gaged watershed to estimate the flow to a similar ungaged watershed. The computed flows for Beaverdam Ditch are scaled based on the drainage area of each watershed.

The discharges calculated using HEC-HMS were higher than the gage data; therefore, the RCNs were reduced by 9 percent. This resulted in an average error of less than 1 percent for the 10- and 25-year flows for Watersheds 1 and 5 compared to the flows computed based on Beaverdam Ditch. The RCNs were reduced because previous studies have found that RCN values in Delaware are typically lower than those calculated using TR-55 methodology due to unique characteristics of the Delaware coastal plain (McCormick Taylor, 2009; GMB, 1998; MRA, 2006; DNREC, 2010). The reduced RCN is consistent with the findings of these studies. The discharges computed as part of the calibration analyses are summarized in Table F-5.

Table F-5: USGS gage 1484695 at Beaverdam Ditch Peak Flow from PeakFQ and Corresponding Oak Orchard Estimates

Name	Accumulated Drainage Area, mi²	Storm Event Flows (cubic feet per second)				
		2-year	10-year	25-year	50-year	100-year
USGS Gage 1484695 at Beaverdam Ditch (from PeakFQ)	2.2	95	253	389	532	726
Predicted flow for Watershed 1 using gage (Outfall 1)	1.53	65	173*	266*	364	496
Calibrated HEC-HMS flow for Watershed 1 (Outfall 1)	1.53	77	169	253	328	413
Predicted flow for Watershed 5 using gage (Outfall 5)	1.25	53	140*	216*	296	403
Calibrated HEC-HMS flow for Watershed 5 (Outfall 5)	1.25	57	146	224	297	381

*The 10- and 25-year peak flows were used for calibration

SUMMARY OF RESULTS

Results of the hydrologic simulations are summarized in Table F-6. Results of the HEC-HMS model are reported by sub-basin name, junctions, and outfalls. The locations of the sub-basins, junctions, and outfalls, are shown in Figure F-2.

Table F-6: Summary of Hydrologic Analysis

Name	Drainage Area, mi²	Storm Event Flows (cubic feet per second)				
		2-year	10-year	25-year	50-year	100-year
S_1A	0.43	47	105	154	201	254
S_1B	1.10	56	122	178	230	289
S_2	0.12	10	22	33	44	57
S_3	0.02	4	10	14	19	24
S_4	0.11	15	33	49	64	81
S_5A	0.09	21	45	67	86	109
S_5A1	0.01	4	9	13	17	22
S_5A2	0.01	4	8	12	16	21
S_5B	0.05	11	24	36	47	59
S_5B1	0.01	3	6	9	12	16
S_5B2	0.02	4	10	15	20	26
S_5C	0.04	5	12	17	23	29
S_5D	0.13	22	47	69	90	113
S_5D1	0.06	10	22	33	44	57
S_5D1A	0.01	2	5	8	10	13

Name	Drainage Area, mi^2	Storm Event Flows (cubic feet per second)				
		2-year	10-year	25-year	50-year	100-year
S_5D2	0.17	17	37	55	72	91
S_5E	0.01	2	4	5	7	9
S_5E1	0.01	3	5	8	10	13
S_5F	0.11	37	78	113	144	179
S_5F1	0.03	6	14	21	27	34
S_5F1A	0.02	2	5	8	11	14
S_5G	0.04	13	27	39	50	63
S_5G1	0.02	4	9	13	17	21
S_5H	0.03	10	20	29	37	46
S_5H1	0.07	10	23	34	44	56
S_5I	0.07	13	28	40	52	65
S_5J	0.25	18	40	61	80	103
S_6	0.01	3	6	9	12	15
S_7A	0.01	2	4	6	9	11
S_7B	0.05	4	10	16	22	28
S_8	0.01	2	5	8	10	13
J_100	1.10	56	122	178	230	289
J_500	1.14	64	156	246	334	436
J_501	1.07	71	168	259	345	445
J_502	1.04	71	174	268	356	457
J_503	0.89	65	150	233	307	389
J_504	0.64	48	109	160	207	261
J_505	0.01	3	5	8	10	13
J_506	0.24	23	52	77	100	127
J_507	0.01	2	5	8	10	13
J_508	0.02	4	10	15	20	26
J_509	0.01	3	6	9	12	16
J_510	0.01	4	8	12	16	21
J_511	0.05	3	15	25	34	43
J_512	0.02	4	9	13	17	21
J_513	0.48	42	91	134	174	220
J_514	0.44	39	87	128	167	211
J_516	0.39	35	77	114	149	190
J_517	0.07	10	23	34	44	56
J_518	0.25	18	40	61	80	103

Name	Drainage Area, mi^2	Storm Event Flows (cubic feet per second)				
		2-year	10-year	25-year	50-year	100-year
J_519	0.03	7	16	24	31	40
J_520	0.02	1	5	8	11	14
J_521	0.01	4	9	13	17	22
J_522	0.07	6	26	41	54	70
J_700	0.05	4	10	16	22	28
Outfall 1*	1.53	77	169	253	328	413
Outfall 2	0.12	10	22	33	44	57
Outfall 3	0.02	4	10	14	19	24
Outfall 4	0.11	15	33	49	64	81
Outfall 5*	1.25	57	146	224	297	381
Outfall 6	0.01	3	6	9	12	15
Outfall 7	0.07	6	13	21	28	36
Outfall 8	0.01	2	5	8	10	13

*Flows used for Runoff Curve Number (RCN) calibration using peak flows computed from Beaverdam Ditch

The USGS Scientific Investigations Report 2006-5146 (Ries and Dillow, 2006) regression equations were used to validate that the results are reasonable. To use these regression equations, a watershed must have a drainage area between 0.51 square mile and 117 square miles, a basin slope between 0.3 percent and 3.7 percent, and between 0.53 percent and 60 percent of the drainage area must be hydrologic soil type A. Watershed 1 is the only watershed that meets all three of these requirements. The computed values at Outfall 1 for the 2-, 10-, 25-, 50-, and 100-year peak flows are all within the 90-percent prediction interval specified by the regression equations.

CONCLUSION

Results from the HEC-HMS model represent conservative estimates suitable for design. The results of this study can be used by DNREC for future stormwater management improvements. Additionally, the results of the hydrology modeling will be used in hydraulic calculations for the proposed projects recommended in the Oak Orchard Coastal Drainage Engineering Evaluation.

REFERENCES

Delaware Department of Natural Resources and Environmental Control (DNREC), 2010. "Hydrologic Analysis of Williams Pond Watershed Sussex County, Delaware in Support of the Nanticoke Watershed Management Plan."

George, Miles & Buhr (GMB), 1998. "Chapel Branch Hydrologic and Hydraulic Study."

ESRI, 2012. ArcGIS Version 10.1. Available at www.esri.com/.

McCormick Taylor, 2009. "Safety Evaluation for Hearns Pond Dam and Williams Pond Dam."

Morris & Ritchie Associates, Inc. (MRA), 2006. "Updated Hydraulic Analysis of Chapel Branch, Tull Gardens."

Natural Resources Conservation Service (NRCS), 1986. *Urban Hydrology for Small Watersheds TR-55*.

NRCS, 2009. U.S. General Soil Survey Geographic Database (SSURGO). Available at http://SoilDataMart.nrcs.usda.gov/, accessed on July 2013.

NRCS, 2010. *Part 630 Hydrology National Engineering Handbook.*

Ries, K.G., III and Dillow, J.J.A., 2006. *Magnitude and Frequency of Floods on Nontidal Streams in Delaware*. Reston, Virginia: U.S. Geological Survey Scientific Investigations Report 2006-5146, available at http://pubs.usgs.gov/sir/2006/5146/pdf/sir2006-5146.pdf.

U.S. Army Core of Engineers (USACE), 2010. *Hydrologic Modeling System HEC-HMS*. Available at http://www.hec.usace.army.mil/software/hec-hms/.

U.S. Geological Survey (USGS), 2015. National Elevation Dataset (NED). Available at http://ned.usgs.gov/.