4. Storm Drainage System Design

4.1 General

The purpose of this section is to focus on the proper hydraulic design of storm drains, the collection system, and appurtenances. The storm drainage system consists of inlets, grates, parking lots, street gutters, roadside ditches, small channels and swales, and underground pipe systems which collect stormwater runoff and transport it to structural control facilities and/or the major drainage system (i.e., natural waterways, large man-made conduits, large water impoundments).

This section provides criteria and guidance for the design of minor drainage system components including:

- Street and roadway gutters
- Stormwater inlets and grates
- Storm drainpipe systems

Roadside ditch, channel and swale design criteria and guidance are covered in Chapter 5, *Open Channel Design*.

Procedures for performing gutter flow calculations are based on a modification of Manning's Equation. Inlet capacity calculations for grate, curb and combination inlets are based on information contained in HEC-22 (USDOT, FHWA, 2009). Storm drainage system design may be based on either the use of the Rational Formula for gutters and inlets, subject to the area limitations provided in Chapter 3, or the SCS or TR-55 methodologies.

4.2 Storm System Design Requirements

In preparation of storm sewer design, the following list of minimum requirements must be prepared for a storm sewer design:

1. Engineering report displaying relevant calculations and design. See Example Report in Appendix A.
2. A plan of the drainage area map at a scale of 1” = 200’ with 10-foot (2-foot minimum) contour intervals using USGS datum for areas less than 100 acres or a plan of the drainage area at a scale of 1” = 500’ with 10-foot (5-foot minimum) contour intervals for larger areas.
3. This plan shall include all proposed street, drainage, and grading improvements with flow quantities and direction at all critical points.
4. All areas and subareas for drainage calculations shall be clearly distinguished.
5. Complete hydraulic data showing all calculations, including a copy of all graphs used for your calculations shall be submitted.
6. A plan and profile of all proposed improvements at a scale of 1” = 50’ horizontal and 1” = 5’ vertical shall be submitted. This plan shall include the following:
    a. Locations, sizes, flowline elevations and grades of pipes, channels.
    b. Boxes, manholes, and other structures drawn on standard plan-profile sheets.
    c. Existing and proposed ground line profiles.
    d. List of the kind and quantities of materials.
    e. Typical sections of all boxes and channels.
    f. Location of property lines, street paving, sanitary sewers, and other utilities.

7. A field study of the downstream capacity is required of all drainage facilities if flows are increased. The effect of additional flow from the area to be improved shall be submitted. If effects endanger property or life, the problem must be resolved before the plan will be given approval. Downstream effects shall be evaluated to the point where the drainage area of the site comprises 10% of the total drainage area.
8. Stormwater flow quantities in the street shall be shown at all street intersections and all inlet openings and locations where flow is removed from the streets.

Stormwater system design shall include the hydraulic calculations for all inlet openings and street capacities. The gutter flow shall be limited according to Section 4.3, Street and Roadway Gutters. Any additional information deemed necessary by the City Design Review Engineer for an adequate consideration of the storm drainage effect on the City of Little Rock and surrounding areas must be submitted.

4.2.1 Design Storm

The design storm for the storm drainage system is based on the road classification in the Master Street Plan. The current version of the Master Street Plan can be found on the City of Little Rock's website: https://www.littlerock.gov/business/planning-and-development/2023-master-street-plan-update-transportation-development/

Design storm requirements are provided in Table 4.1. The full build-out conditions shall be used to calculate flows for the appropriate design storm frequencies. Reasonable assumptions must be made for off-site flows. The 100-year design storm event shall be used as the check storm to estimate runoff for routing to evaluate effects on the facilities, adjacent property, floodplain encroachment and downstream areas. For the 100-year event, ensure that storm pipe systems will safely convey flows that are in excess of pipe design flows without damaging structures or flooding major roadways. The 100-year storm shall not be conveyed through driveway cuts or across private property but shall remain within the ROW and/or a drainage easement. No fences, portable storage buildings, large landscaping features (i.e., boulders, decorative rock), or other obstructions may be placed within drainage easements.

*Table **Error! No text of specified style in document.**.7 Design Storm for Street Classification*

Street Classification	Design Storm
Principal Arterials	100-year
Major and Minor Arterials	100-year
All other streets	25-year

Note: 100-year flow path shall be used for all systems in the right of way (ROW)

4.3 Street and Roadway Gutters

The location of inlets and permissible flow of water in the streets should be related to the extent and frequency of interference to traffic and the likelihood of flood damage to surrounding property. Effective drainage of street and roadway pavements is essential to pavement longevity and traffic safety. Surface drainage is a function of transverse and longitudinal pavement slope, pavement roughness, inlet spacing, inlet capacity, and adequate subsurface drainage. The design of these elements is dependent on storm frequency and the allowable spread of stormwater on the pavement surface. To compute gutter flow, the Manning's equation is integrated for an increment of width across the section. The resulting gutter equation is:

$$Q = (K_u/n) S_x^{1.67} S_L^{0.5} T^{2.67} \qquad \textbf{Eq. 4.1}$$

Where: Q = flow rate

K_u = 0.56

n = Manning's coefficient (Table 4.2)

S_x = Cross slope (ft/ft)

S_L = Longitudinal slope (ft/ft)

T = Width of flow (spread) (ft)

Table 4.2 Manning's n for Street and Pavement Gutters.

Type of Gutter or Pavement	Manning's n
Concrete gutter, troweled finish	0.012
Asphalt Pavement:	
Smooth texture	0.013
Rough texture	0.016
Concrete gutter-asphalt pavement:	
Smooth	0.013
Rough	0.015
Concrete pavement:	
Float finish	0.014
Broom finish	0.016
For gutters with small slope, where sediment may accumulate, increase above values of "n" by	0.002

Source: HEC-22

4.3.1 Permissible Spread of Water

Inlets shall be installed at low points and at such intervals to provide the appropriate clear traffic lane per street classification in each direction based upon peak discharges from the design storm. Minimum lane clearance requirements are provided in Table 4.3. All computations for the design storm and 100-year, 24-hour storm shall be provided.

*Table **Error! No text of specified style in document.**.3 Flow Spread Limits for Inlets*

Street Classification	Minimum clear space
Principal and Arterial Streets	Two 12-feet traffic lanes, one in each direction, independent of curb and gutter
Collector Streets	One 12-feet traffic lane within 6 feet of roadway centerline
All other streets	One 10-feet traffic lane within 4 feet of roadway centerline

4.3.2 Flow Bypass

Bypass flow occurs when storm sewer inlets do not capture 100% of the flow upstream of their location. A variety of factors, including organic debris, gutter flow rate, longitudinal slope, and inlet type/geometry, play a role in the capture efficiency of an individual inlet. Flow bypassing each inlet must be included in the total gutter flow to the next inlet downstream. A bypass of 10 to 20% per inlet will result in a more economical drainage system.

4.3.3 Minimum and Maximum Velocities

To ensure cleaning velocities at very low flows, the gutter shall have a minimum longitudinal slope of 0.005 feet per foot (0.5%).

The maximum velocity of gutter flow shall be 10 feet per second. Along sharp horizontal curves, peak flows tend to jump behind the curb line at driveways and other curb breaks. Water running behind the curb line can result in considerable damage due to erosion and flooding. Inlets should be placed upstream of horizontal curves to capture gutter flow and limit flow along the curve.

4.4 Storm Drain Inlets

The primary purpose of storm drain inlets is to intercept excess surface runoff and deposit it in a drainage system, thereby reducing the possibility of surface flooding.

The most common location for inlets is in streets which collect and channelize surface flow making it convenient to intercept. Because the primary purpose of streets is to carry vehicular traffic, inlets must be designed so as not to conflict with that purpose.

The following guidelines shall be used in the design of inlets to be located in streets:

1. Grate inlets shall not be used in a roadway.
2. Inlets shall not be placed on the radius of a curve.
3. Placing inlets downstream of a radius should be avoided.
4. Design and location of inlets shall take into consideration pedestrian and bicycle traffic.
5. Inlet design and location must be compatible with the spread limitations presented in Table 4.3.

4.4.1 Classification

Inlets are classified into three major groups, mainly: inlets in sumps (Type A), inlets on grade without gutter depression (Type B), and inlets on grade with gutter depression (Type C). Each of the three major classes include several varieties, shown in Table 4.4. Recessed inlets are identified by the suffix (R, i.e.: A-1 (R)). The term "continuous grade" or "on grade" refers to an inlet located on the street with a continuous slope past the inlet with water entering from one direction. The "sump" condition exists when street grade is less than 1% or the inlet is located at a low point allowing water to enter from both directions.

*Table **Error! No text of specified style in document.**.4 Stormwater Inlet Types*

Inlets in Sumps	
Type A-1	Curb Opening
Type A-2	Grate
Type A-3	Combination (Grate and Curb Opening)
Type A-4	Drop
Type A-5	Drop (Grate Covering)
Inlets on Grade Without Gutter Depression	
Type B-1	Curb Opening
Type B-2	Grate
Type B-3	Combination (Grate and Curb Opening)
Inlets on Grade with Gutter Depression	
Type C-1	Curb Opening
Type C-2	Grate
Type C-3	Combination (Grate and Curb Opening)

The Department of Planning and Development review of a proposed drainage plan shall include examination of the supporting inlet computations. Computations must be submitted on separate tabulations sheets convenient for review and use of a permanent record in order to speed review.

4.4.2 Inlets in Sumps

Inlets in sumps are inlets placed in low points of surface drainage to relieve ponding. Inlets with a 5-inch depression located in streets of less than one percent (1.0%) grade, shall be considered inlets in sumps. The capacity of inlets in sumps must be known in order to determine the depth and width of ponding for a given discharge. Capacity calculations should be based on HEC-22 methodology or manufactures capacity curves.

Inlets in sumps function like weirs for shallow depths. The hydraulic capacity of a curb opening inlet or a vaned grate inlet operating as a weir is expressed as:

$$Q_i = C_w L_w d^{1.5} \qquad \textbf{Eq. 4.2}$$

Where: Q_i = inlet capacity (CFS)

C_w = weir discharge coefficient

Lw = weir length (ft), length of inlet opening acting as a weir

d = flow depth (ft)

Curb opening inlets and drop inlets in sumps have a tendency to collect debris at their entrances. For this reason, the calculated inlet capacity shall be reduced by 20 percent to allow for clogging. Grate inlets have a tendency to clog when flows carry debris such as leaves and papers. For this reason, the calculated inlet capacity of a grate inlet shall be reduced by 50 percent to allow for clogging.

Table 4.5 Sump Inlet Discharge Variables and Coefficients for weir inlets.

Weir Inlet Types	C_w	L_w	Weir equation valid for
Curb opening inlet	3.00	L	d < h
Recessed curb opening inlet	2.30	L+1.8W*	d < h + a
Vane Grate Inlet	3.00	L+2W	d < 1.79 (A_o/L_w)

Definition of terms:

L = length of curb opening

h = height of curb opening

d = depth of water at curb opening

W* = lateral width of recessed section

a = depth of curb depression

Ao = clear opening area

W = width of grate

As the depth of stormwater increases, inlet sumps begin to function like an orifice. HEC-22 provides guidance on the transition region based on significant testing. At depths above 1.4 times the opening height, the inlet operates as an orifice and between these depths, transition between weir and orifice flow occurs. The hydraulic capacity of a curb opening inlet or a vane grate inlet operating as an orifice is expressed as:

$$Q_i = C_o A_o \sqrt{2gd} \qquad \textbf{Eq. 4.3}$$

Where: Q_i = inlet capacity (cfs)

C_o = orifice coefficient

A_o = orifice area (ft^2)

g = gravitational acceleration (32.2 ft/sec^2)

d = characteristic depth (ft) defined in Table 4.6

Table 4.6 Sump Inlet Discharge Variables and Coefficients for orifice inlets.

Orifice Inlet Types	C_o	A_o	Orifice equation valid for
Curb opening inlet or recessed curb opening inlet	0.67	hL	di* > 1.4h
Vane Grate Inlet	0.67	Clear opening area	d** > 1.79(Ao/Lw)

* di = depth of water at curb opening

** d = depth of water over grate

Note: The orifice area (A_o) should be reduced where clogging is expected.

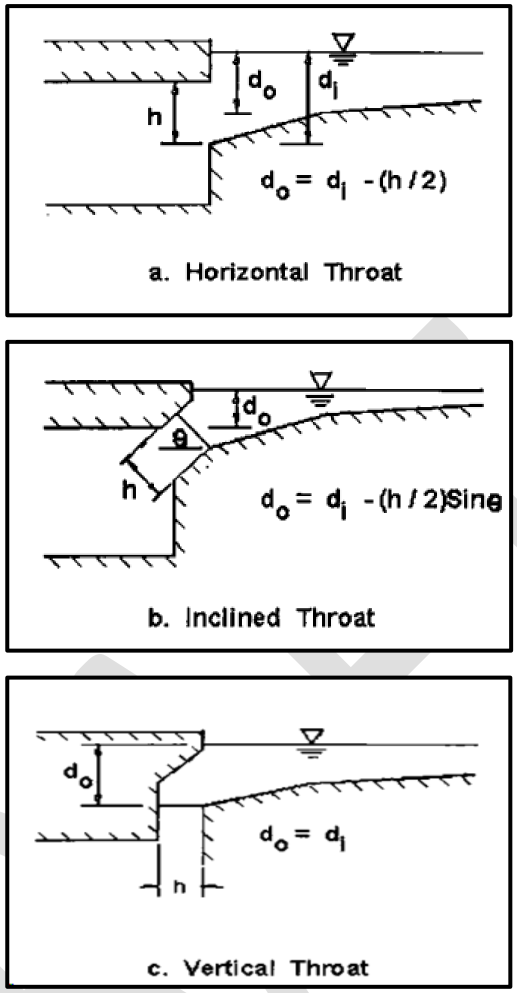

Figure 4.1 Curb-Opening Inlets

4.4.3 Inlets on Grade

Curb opening inlets are effective in the drainage of roadway pavements and in parking lots where flow depth at the curb is sufficient for the inlet to perform efficiently. Curb openings are relatively free of clogging tendencies and offer little interference to traffic operation. Street inlets shall be depressed 4 inches with a 12-feet transition upstream and 4-foot transition downstream. Where stormwater flow approaches an arterial street or tee intersection, an inlet is required.

Inlet dimensional requirements: clear throat opening shall be 6 inches in height and 4-feet minimum length. For all throat extensions, clear dimensions shall be 6 inches in height and 3 feet, 6 inches in length. City of Little Rock standard drawings and details shall be used.

Inlets with extensions shall have a maximum clear opening dimension that complies with the City of Little Rock standard drawings. For inlets with extensions, the spacing of 4-inch stools shall not exceed 4 feet in length. If additional length is needed to accommodate City spread and ponding depth requirements, additional inlets shall be added upstream. No clogging factor is required to be applied for curb inlets on grade. For calculation of the interception capacity of inlets on grade, refer to HEC-22.

Flow bypassing each inlet must be included in the total gutter flow to the inlet downstream. A bypass of 10 to 20 percent per inlet will result in a more economical drainage system.

4.4.4 Combination Inlets

The capacity of a combined inlet Type A-3 consisting of a grate and curb opening inlet in a sump shall be considered to be the sum of the capacities. When the capacity of the gutter is not exceeded, the grate inlet accepts the major portion of the flow. Under severe flooding conditions the curb inlet will accept most of the flow.

Combination inlets and sumps have a tendency to clog and collect debris at their entrance. For this reason, the calculated grate capacity of the inlet shall be reduced by 50 percent to allow for this clogging.

4.4.5 Plan and Calculation Submittals

It is important to carefully track runoff flow rates, bypassing flow rates, flow spreads, and other parameters related to gutter flow and inlet capacity for all design storms. Details of grate inlets, net opening, and ratings curves are required to be turned in to the Department of Planning and Development.

4.5 Flow in Storm Drains

Storm drainpipe systems, also known as storm sewers, are pipe conveyances used in the stormwater drainage system for transporting runoff from roadway and other inlets to outfalls at structural stormwater controls and receiving waters. Pipe drain systems are suitable mainly for medium to high-density residential and commercial/industrial development where the use of natural drainageways and/or vegetated open channels is not feasible.

There are several general rules to be observed when designing storm sewer systems. When followed, they will tend to alleviate or eliminate the common issues made in storm sewer design. These rules are as follows:

1. Select pipe size and slope so that the velocity of flow will increase progressively, or at least will not appreciably decrease at inlets, bends or other changes in geometry or configuration. A 15" pipe diameter is the minimum acceptable pipe diameter for maintenance purposes.
2. Do not discharge the contents of a larger pipe into a smaller one, even though the capacity of the smaller pipe may be greater due to steeper slope.
3. At changes in pipe sizes, match the soffits of the two pipes at the same level rather than matching the flow lines.
4. Conduits are to be checked at the time of their design with reference to critical slope. If the slope of the line is greater than critical slope, the unit will likely be operating under entrance control instead of the originally assumed normal flow. Conduit slopes should be kept below critical slope if at all possible. This also removes the possibility of a hydraulic jump within the line.

4.5.1 Hydraulic Grade Line

The water surface elevation, or hydraulic grade line, shall be at least 1 foot below the inlet throat elevation for the design flow. Where required, adjustments shall be made in the system to reduce the elevation of the hydraulic grade line to meet this requirement. All head losses in a storm sewer system including minor losses are considered in computing the hydraulic grade line to determine the water surface elevations, under design conditions, in the various inlets, catch basins, manholes, junction boxes, etc. The starting elevation of the hydraulic grade line shall be set to the tailwater elevation of the receiving stream or waterbody matching the design storm. For example, if the storm pipe system is designed for the 25-year storm, then the tailwater elevation shall be based on the 25-year storm elevation in the receiving channel.

4.5.2 Roughness Coefficients

Any storm drainpipe located in a right-of-way or drainage easement shall be reinforced concrete pipe (RCP) except for side drains which are allowed to be high density polyethylene (HDPE).
Table 4.7 below should be used for Manning's n-values for conduits.

4.5.3 Manhole Location

Manholes shall be located at intervals not to exceed 500 feet. Manholes shall preferably be located at street intersections, conduit junctions, changes of grade, changes of horizontal alignment and all changes of pipe sizes. For manholes and junction boxes deeper than 3 feet, steps shall be added.

4.5.4 Minor Head Losses at Structures

The following total energy head losses at structures shall be determined for inlets, manholes, wye branches or bends and the design of closed conduits. Minimum head loss used at any structure shall be 0.10 foot, unless otherwise approved. The basic equation for most cases, where there is both upstream and downstream velocity, takes the form as seen below with the various conditions of the coefficient of K_j shown in Tables 4.8 and 4.9.

$$h_j = K_j \frac{|V_2{}^2 - V_1{}^2|}{2g}$$ **Eq. 4.4**

Where: h_j = Junction or structure head loss and feet.

V_1 = Velocity in upstream pipe and feet per second.

V2 = Velocity in downstream pipe and feet per second.

K_j = Junction or structure coefficient of loss.

In the case where the initial velocity is negligible, the equation for head loss becomes:

$$h_j = K_j\left(\frac{V^2}{2g}\right)$$ **Eq. 4.5**

Short radius bends may be used on 24 inch or larger pipes where flow must undergo a direction change at a junction or bend. Reductions in head loss at manholes may be realized in this way. A manhole shall always be located at the end of such short radius bends.

*Table **Error! No text of specified style in document.**.7 Manning's n-values for conduits.*

Conduit Material	Manning's n-value
Steel:	
Lockbar and welded	0.012
Riveted and spiral	0.016
Cast Iron:	
Coated	0.013
Uncoated	0.014
Wrought Iron:	
Black	0.014
Galvanized	0.016
HDPE:	
Smooth	0.012
Corrugated	0.024
Corrugated Metal:	
Storm Drain	0.024
Cement:	
Neat, surface	0.011
Mortar	0.013
Concrete:	
Culvert, straight and free of debris	0.011
Culvert with bends, connections, and some debris	0.013
Sewer with manholes, inlet, etc., straight	0.015
Unfinished, steel form	0.013
Unfinished, smooth wood form	0.014
Unfinished, rough wood form	0.017
Wood:	
Stave	0.012
Laminated, treated	0.017
Brickwork:	
Lined with cement mortar	0.015
Sanitary sewers coated with sewage slime with bends and connections	0.013
Paved invert, sewer, smooth bottom	0.019
Rubble masonry, cemented	0.025

Source: Chow, 1959

The values of the coefficient K_j for determining the loss of head due to obstructions in pipe are shown in Table 4.8 and the coefficients are used in the previous equation to calculate the head loss at the obstruction. The values of the coefficient K_j for determining the loss of head due to sudden enlargements and sudden contractions in pipes are shown in Table 4.9 and the coefficients are used in the previous equation to calculate the head loss at the change.

*Table **Error! No text of specified style in document.**.8 Minor Loss Coefficients.*

Type of Obstruction	Coefficient (K_j)
22.5-Degree Bend	0.20
45-Degree Bend	0.35
60-Degree Bend	0.43
90-Degree Bend	0.50
Straight through Manhole	0.05
Inlet on main line	0.50
Inlet on main line with a lateral branch	0.25

*Table **Error! No text of specified style in document.**.9 Minor Loss Coefficients for Junctions.*

Type of Junction	Coefficient (K_j)
Junction or manhole on main line with a 22.5-degree lateral branch	0.75
Junction or manhole on main Line with a 45-degree lateral branch	0.50
Junction or manhole on main line with 60-degree lateral branch	0.35
Junction or manhole on main line with 90-degree lateral branch	0.25
Inlet entrance	1.25
Conduit Projecting from Fill, Socket End (Groove End)	0.20
Projecting from Fill, Square Cut End	0.50
Socket End of Pipe (Groove-End)	0.20
Square-Edge	0.50
Rounded	0.20
Mitered to Conform to Fill Slope	0.70

Source: Brazoria County, Texas Drainage Manual

4.5.5 Minimum Grades

Storm drains should operate with velocities of flow sufficient to prevent excessive deposition of solid material; otherwise, objectionable clogging may result. The controlling velocity is near the bottom of conduits and considerably less than the mean velocity. Storm drains shall be designed to have a minimum velocity flowing full of 2.5 feet per second (fps). Table 4.10 indicates the grades for both concrete pipe (n = 0.013) and for HDPE pipe (n = 0.024) to produce a velocity of 2.5 fps, which is considered to be the lower limit of scouring velocity. Grades for closed storm sewers and open paved channels shall be designed so that the velocity shall not be less than 2.5 fps nor exceed 12 fps. All other structures such as junction boxes or inlets shall be in accordance with City standard drawings. The minimum slope for standard construction procedures shall be 0.40 percent when possible. Any variance must be approved by the Director of Planning and Development. Closed storm sewers extending to furthest downstream point of development shall consider velocities and discharge energy dissipaters to prevent erosion and scouring along downstream properties.

*Table **Error! No text of specified style in document.**.10 Minimum slope required to produce scouring velocity.*

Pipe Size (Inches)	Concrete Pipe Slope ft/ft	Corrugated HDPE Pipe ft/ft
15	0.0023	0.0076
18	0.0018	0.0060
21	0.0015	0.0049
24	0.0013	0.0041
27	0.0011	0.0035
30	0.0009	0.0031
36	0.0007	0.0024
42	0.0006	0.0020
48	0.0005	0.0016
54	0.0004	0.0014
60	0.0004	0.0012
66	0.0004	0.0011
72	0.0003	0.0010
78	0.0003	0.0009
84	0.0003	0.0008

4.5.6 Utilities

In the design of a storm drainage system, the engineer is frequently confronted with the problem of grade conflict between the proposed storm drain and existing utilities, such as communications, water, gas, and sanitary sewer lines. When conflicts arise between a proposed drainage system and utility system, the owner of the utility system shall be contacted and made aware of the conflict. Any adjustments necessary to the drainage system or the utility can then be determined.

Due to the difficulty and expense to the public with regard to hand cleaning, clearing, and other ditch maintenance, the following ditch requirements are specified to expedite small equipment cleaning and access to drainage easements and ditches:

- Manholes are not allowed in drainage ditches.
- Access Easements shall be required every 500 feet.
- Utility Crossings (above the channel flowline) shall be limited to one per block.
- Utilities shall not be located beneath a concrete bottom except at crossings.

4.5.7 Easements

Drainage easements shall be provided in accordance with the following requirements:

- Drainage easements shall be a minimum of 20 feet.
- For pipe or culverts less than 36-inch in diameter or width, the drainage easement shall be measured from the center of the pipe or culvert. For pipes or culverts greater than 36-inch

diameter or width, the easement shall be a minimum of 10 feet from the outside edges of the pipe or culvert.

Minimum widths given above are for installations with depths of cover of 10-feet or less (measured at the top of pipe). For each additional 5-feet of cover over 10-feet (rounded up), the minimum easement width shall be increased by 10-feet.

4.6 References

Flood-Control-and-Water-Quality-Protection-Manual-April-2022 (springfieldmo.gov)