IOWA DOT

Design Bureau

4A-10

Storm Sewer Design

Design Manual
Chapter 4
Drainage

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General

This section will assist in understanding the principles, assumptions, and design criteria required for storm sewer design to assist in computer modeling and checking.

The Iowa DOT requires computerized modeling design using Geopak Drainage.

Design in Geopak Drainage is desired for many reasons including:

- Uniform use of design drainage library components.
- Facilitation of running and evaluating alternate design storms, scenarios, and criteria.
- Evaluation of flow regimes. Hand calculations generally ignore or do not adequately evaluate junction losses at structures and/or velocity changes within pipes. Not all flows are subcritical, steady, uniform, etc. Models can help determine where flow regimes may be critical.
- Evaluation of the hydraulic grade line (HGL) and tailwater conditions that are related to the previous bullet item as well as other constraints.
- Facilitation in plan preparation and reporting.

CADD: See Sections 4A-55 and 4A-57 for instructions on adding pipes and drawing pipe profiles.

Excel spreadsheets and hand calculations are useful for design checks; however, due to the various scenarios and flows required to be evaluated and the need to evaluate the HGL, spreadsheets and hand calculations should not be used as design tools.

Storm sewer systems are designed after intake types, locations, and sizes have been identified. The designer should consider such items as roadway classification, design traffic, cost, and safety (risk) in the design analysis. Placement and discharges of storm sewers should be designed to take into consideration potential damage to adjacent and downstream properties.

Before beginning storm sewer design:

- Verify maximum structure spacings are not exceeded. Refer to Section 4A-4 for requirements.
- Fully understand concerns and issues related to redirecting flow (taking flow – including the consideration of bypass flow – from one drainage basin to another,) or discharge to undefined drainage ways. Document reasons for doing so along with design considerations.
- Determine downstream controlling conditions including: Outfall Conditions, Tailwater Conditions, Downstream Erosion Potential and Runoff Reduction.
- Determine the existing and desired maximum high water elevation (HWE) at critical locations within the system. These locations may include intakes, or anyplace where there is access to the system. The design maximum HWE should not interfere with the intended function of any opening nor should it reach a manhole cover.

For pipes under railroads, contact Iowa DOT Office of Rail Transportation.

For footing drains or other urban connections to the storm sewer system, refer to SUDAS design criteria.

A section of storm sewer connecting one intake or manhole to another is often called a “run” or “link”. A storm sewer system is designed from run to run. Design generally begins at the upstream end (or reach) of the system and proceeds down to the outlet. The process for determining the HGL begins at the outlet and works upstream. Downstream tailwater conditions – the water surface elevation of the receiving channel – may affect the design as well. Thus the overall design process is often iterative.

Hydraulic design of storm sewer systems requires an understanding of basic hydrologic and hydraulic concepts and principles. Refer to HEC-22 Chapters 3 and 5 for a review of some basic hydraulic principles. This section assumes a basic understanding of these principles.

Design of storm sewer systems generally assumes open channel flow for the minor storm event. To maintain open channel flow, the system must be sized so that the water surface remains open to atmospheric pressure (i. e. the flow depth is less than the pipe diameter). For this to happen, the HGL must be contained within the pipe. Consideration of pressure flow is allowed for the major storm event. In pressure flow, the hydraulic grade line will be higher than the pipe diameter.

Simple storm sewer design involves several assumptions such as steady and uniform gravity flow, junction losses in intakes and manholes, outlet conditions, etc. Equations and methods used for design are empirical and contain coefficients and assumptions. Existing systems should be investigated, evaluated, modeled, and calibrated before upgrading them or adding to them. An evaluation of the existing system profile along with an understanding of existing drainage concerns will assist in estimating the desired modeling extents. Design work and/or modeling may result in the determination of additional design/modeling needs.

Storm drains are expensive and permanent elements that are often very costly to replace, especially if replacement affects pavement, intakes, or other infrastructure. At a minimum, design models should be checked and verified by an individual experienced with storm sewer drainage design. When possible, alternate methods or models should be used to check designs. When results differ significantly between methods or models (more than 5 to 10 percent), the methods or models should be investigated to determine what may be causing the differences and why.

Complex designs including but not limited to: detention basins, pump stations, complex networks, and/or systems with notable drainage concerns may require dynamic hydrograph routing computer modeling. Methods used for Dynamic modeling are to be approved by the Department for the specific project or task.

The remainder of this section discusses the following:

- Design Criteria
- Outfall Conditions
- Tailwater Conditions
- Downstream Erosion Potential and Runoff Reduction
- Hydraulic Grade Line
- Pressure Flow Design
- Check for Major Storms
- Intake and Manhole Sizing
- Filling in Tabulation 104-5B
- Design Documentation and Reporting

Design Criteria

Design criteria are summarized below with more in-depth discussion following.

- Location and Horizontal Alignment: Refer to discussion.

- Type of Pipe: Assume concrete pipe with a Manning's n = 0.013.
- Minimum Pipe Size: 15 inch diameter. 24 inch diameter under Interstate pavement.
- Minimum Cover: Refer to discussion.
- Minimum Vertical Drop at Structures:
  - Equal pipe sizes: 0.3 feet is preferred, but 0.1 feet is allowed.
  - Changing pipe sizes: match soffit elevations.
- Minimum Pipe Grades: For construction purposes, a slope greater than 0.4% is preferred. Initial estimates may use the average slope of the ground. Use 1% minimum grade for cross runs and stubs.
- Pipe Flow
  - Assume 100% intake capture. Add possible bypass flow from other systems and off-site locations.
  - Minor Storm: Flow remains within pipe.
  - Major Storm: Pressure flow allowed if hydraulic grade line remains below intakes and manhole lids.
  - Pipe Friction Loss: Use 0.013 for Manning's n for concrete pipe. Follow jurisdictional requirements for other pipe types.
- Design Velocity
  - Within pipe system:
    - Minimum: 3 fps for cleaning velocity using a 5 year (Q_5) recurrence interval.
    - Maximum: 15 fps calculated at the minor storm event and evaluated at the major storm.
  - Maximum Outfall Velocity: Refer to discussion.
- HGL: Refer to discussion.
- Crossings and Clearances (clearance is defined as outside of pipe to outside of pipe):
  - From Sanitary Sewer Mains: Minimum horizontal clearance is 5 feet. Minimum crossing vertical clearance is 6 inches with special structural support required at less than 18 inches. Clearance is defined as outside of pipe to outside of pipe.
  - From Water mains: Minimum horizontal clearance is 10 feet. Minimum crossing vertical clearance is 18 inches. Location and Horizontal Alignment

Design and place storm sewer with straight alignments between structures.

Parallel to street: Place storm sewer behind the curb as much as practical.

Transverse: Connect each end with to intake, manhole, or outfall.

Place public storm sewer systems located outside of the State right-of-way (ROW) in a storm sewer easement. Storm sewer easements should have a minimum width of 20 feet or two times the depth of the sewer (measured to bottom of trench), whichever is greater. The storm sewer should be centered in the easement. Additional width may be required by the Jurisdictional Engineer for maintenance purposes. Consideration needs to be given to future pipe repairs when considering easement locations and widths.

Where street layouts are curved with a radius of curvature greater than 200 feet and the storm sewer is 48 inches in diameter or greater, consideration may be made for a curved sewer using factory fabricated pipe bends. Consideration needs to be made for cost, available standard long radius curve sizes, and pipe industry recommended maximum deflection angle.

Refer to the SW Series of the Standard Road Plans for location stations of intakes and manholes.

Type of Pipe

Design assuming concrete pipe. Concrete pipe is required under the pavement for all Primary and Interstate Highways, except non-NHS highways where ADT is less than 3,000. Assume a Manning's roughness coefficient n = 0.013. Use the strength (class) and wall type required by the Standard Specifications and Standard Road Plans. The designer should evaluate the application with respect to the design fill height, ground water table, and other standard design considerations. Design examples in this section are based on concrete pipe. When a local jurisdiction allows another type of pipe outside of Primary Highway pavement, use SUDAS design criteria for the alternate pipe.

For trenchless installation, refer to Section 2553 of the Standard Specifications. For footing drain design considerations, refer to SUDAS for design criteria.

Minimum Cover

Under pavement: Top of pipe at least 1.0 foot below the bottom of subbase. If the pipe does not meet this requirement, adjust it until it does, or provide a design method to maintain the integrity of the pipe and pavement. Special design may include consideration of higher classification of pipe with flowable mortar backfill or other design measures.

Outside of pavement: 3.0 feet of cover is recommended. A minimum of 1.5 feet is required. Justification is required for less than 1.5 feet of cover.

> **Note:** Section 1B-5 provides pipe wall thicknesses to assist with the evaluation of minimum cover.

Minimum Vertical Drop at Structures

The flow line (invert elevation) of a pipe is located at the inside bottom of the pipe opening. The soffit (crown, overt) of a pipe is located at the inside top of the pipe.

To avoid trapping water, the Flow Line In elevation of a pipe taking flow from a structure should be lower than the flow lines of all upstream pipes entering the structure. Use the following criteria:

- When the outgoing and incoming pipes are the same diameter, drop the flow line 0.30 feet where possible. A drop of 0.10 feet is allowed where 0.30 feet cannot be achieved.
- When the diameter of the outgoing pipe is larger than the incoming pipes, align the soffits of the pipes. Where there are more than two inlets, generally the elevation of the soffit of the pipe leaving the structure will be aligned with the soffit of the largest pipe entering the structure.

These are the minimum elevation drops. On steeper grades, it may be necessary to make elevation drops larger in order to reduce the slope and keep water velocity under the scour velocity (15 ft/sec).

Minimum Pipe Slopes

Pipe velocity sets minimum slopes for storm sewer. However, for construction purposes, a slope greater than 0.4% is preferred. Initial estimates may use the average slope of the ground unless this would be unreasonable (such as in bluff areas). Use 1% minimum slope for cross runs and stubs.

Steep grades may result in flow transitioning from subcritical (tranquil) to supercritical (rapid) within a pipe, greatly affecting the velocity in the pipe. Caution and hydraulic understanding are required when working with pipes on steep grades. Computer modeling may assist in determining hydraulic issues and concerns.

Pipe slope is calculated using the difference between the inlet and outlet flowline elevations divided by the horizontal distance measured from inside wall of the upstream structure to inside wall of the downstream structure. The actual required length of a pipe for construction is calculated along the slope of the pipe. To make measurement easier for payment purposes, the Department measures along the ground from center of structure to center of structure. Therefore, the measured payment length is often different from the required installation length. The designer should ensure that pipe lengths used in the design provide the appropriate pipe design slope value, which in turn is used to determine the pipe design velocity and capacity.

Pipe Flow

Maximum pipe flow capacity occurs at approximately 93% of the height of the pipe. This means that if the pipe is designed for full flow, the design will be slightly conservative. Pipe sizing should assume 100% capture at intakes. Do not decrease the size of pipe in the downstream direction, except for special situations such as detention or retention facilities. Geopak Drainage can help with determining initial pipe size estimates. Simple calculations may also be run using the procedure discussed in Sizing Pipes below.

As part of the storm sewer sizing analysis, evaluate bypass flow to other systems and impacts to those systems. When evaluating a portion of a system, be sure to include the flow contribution from the upstream watershed.

Special consideration may be required for pipes at sag locations. Sag intakes are designed assuming no plugging. Flanking intakes are added after the intake design is completed. Therefore the intake design analysis basically assumes no flow to the flanking intakes. For pipe design, the designer needs to assume the sag intake is completely plugged and 50% of its flow is captured in each of the two flanking intakes. Piping from flanking intakes should accommodate 100% of the flow to that intake plus 50% of any additional flow between that intake and the sag intake. This design requires inputting different design values into GEOPAK drainage to evaluate the different intake and pipe scenarios.

Design pipes connecting flanking intakes and sag intakes assuming 50% of the flow to the sag intake is captured at each flanking intake (i.e. assume the sag intake is completely plugged).

Sizing Pipes

Pipes are often evaluated using Manning's Equation modified for circular pipes:

$$Q_{full} = \pi\left(\frac{K_u}{n}\right)\left(\frac{D^{2.67}}{4^{1.67}}\right)\sqrt{S} \qquad \text{(Equation 4A-10\_1)}$$

where:

Q_{full} = Circular pipe full flow capacity, ft^3/s.

S = Slope, ft/ft.

n = Manning's roughness coefficient, Use 0.013 for concrete pipe.

K_u = Units conversion factor, 1.49.

D = Inside diameter of pipe, ft.

Note: Full flow capacity is the capacity exactly at the point when the pipe begins to run full, but before pressure flow begins. It does not include pressure flow which also generally has pipes flowing full.

This equation does not account for things such as inlet or outlet control, pressure flow, special flow conditions, etc. The user should be familiar with the limitations of its use. For other pipe shapes refer to HEC-22.

To use Equation 4A-10_1:

1. Assume a pipe diameter and slope (or check an existing pipe)
2. Solve for Q_{full}, which is the estimated capacity of this pipe at full flow.
3. If Q_{full} is less than the design Q, adjust the slope, pipe size, or both until Q_{full} is greater than the design Q.

Because Equation 4A-10_1 has three independent variables (slope, diameter, flow), two of these variables may be known or assumed to solve for the third. Solving for D the equation becomes:

$$D = 0.263\left(\frac{Q^{0.375}}{S^{0.1875}}\right) \qquad \text{Equation 4A-10\_2}$$

Where Q may be the design flow and D and S are the same as in Equation 4A-10_1. To use Equation 4A-10-2:

1. Solve for D using the design flow and assumed or known slope.
2. Round the answer up to the next standard pipe size.

Note: Adjustments to the size of pipe or slope must maintain the velocity within acceptable parameters.

Design Velocity

A self-cleaning velocity should be maintained to reduce the buildup of sediment that may lead to loss of capacity. For this reason, storm sewer systems are designed to maintain a minimum velocity of 3 ft/s or greater. This should be checked using a 5-year recurrence interval. This is most readily verified using computer modeling. In addition it is desirable to reduce junction losses and minimize flow transitions between subcritical and supercritical, which is why there is a maximum velocity value within systems (this is different than the maximum desired velocity at the outfall).

At the outlet:

- With a flared end (apron) section: Maximum of 5 ft/s and evaluate downstream scour potential to determine if energy dissipation and/or scour measures are required.
- With flared end section, footing and rip-rap, or other approved scour countermeasure: Maximum of 10 ft/s and evaluate downstream erosion potential.
- With energy dissipation device: Maximum of 15 ft/s and evaluate downstream erosion potential.

Equation 4A-10_3 can be used to determine full flow velocity in a circular pipe (assuming full, steady, uniform flow):

$$V_{full} = \frac{Q_{full}}{A} = \left(\frac{K_u}{n}\right)\left(\frac{D}{4}\right)^{0.67}\sqrt{S} \qquad \text{(Equation 4A-10\_3)}$$

where:

V_{full} = Velocity of full flow, ft/s.

A = End Area of pipe (πr^2), ft^2.

Q_{full}, S, n, K_u, and D are the same as in Equation 4A-10_1.

Partial pipe flow velocity can be much greater than the full pipe flow velocity, because at full flow there is more pipe friction acting on the water, thus slowing it down. As discussed under pipe flow, full flow is not to be confused with pressure flow. Computer modeling is the most efficient method to evaluate pipe velocity and the impacts that slope and pipe diameter have on it. The Flow Elements Chart can be used (as discussed below) to evaluate or estimate partial flow velocities in pipes. Adjust the diameter and slope until the partial flow velocity in the pipe falls between the minimum and maximum values.

Chart 4A-10_1, Flow Elements Chart

1. Select a preliminary pipe size using known Q_{design}.
2. Assume a slope (generally begin with ground slope).
3. Use Equation 4A-10_2 to solve for pipe diameter D.
4. Select a standard pipe size greater or equal to D.
5. Determine Q_{full} for the selected D.

6. Determine $\frac{Q_{design}}{Q_{full}}$.

4. Using the result from step 6, look up $\frac{V_{design}}{V_{full}}$ in the Flow Elements Chart.

5. Determine design flow velocity:

$$V_{design} = \frac{V_{design}}{V_{full}} \times V_{full}$$

The following example demonstrates the process.

Example Problem 4A-10_1, Pipe Velocity and Time

Time in Pipe

Time in Pipe (T_{pipe}) is calculated as:

$$T_{pipe} = \frac{L}{60V_{design}} \qquad \text{(Equation 4A-10\_4)}$$

where:

T_{pipe} = time in pipe, minutes

L = Pipe Length, ft

V_{design} = Design Velocity, ft/s

Section 4A-5 provides a worksheet and examples for calculating overland T_c.

Example 4A-10_1, Pipe Velocity and Time

Time of Concentration (T_c) for pipe systems should consider and use the greater of:

- T_c for the upstream intake plus time in pipe.
- T_c for the intake.

Example 4A-10_2, Evaluation of System Time of Concentration

HGL

The HGL is a line coinciding with the water level in the system.

- For the minor storm, the HGL must be within the pipes.
- For the major storm, the HGL must be below intake form grade elevations and manhole lid elevations.

Outfall Conditions

All storm sewer systems have an outlet to which they discharge. The discharge point can be a natural stream, a ditch, an existing storm sewer system or culvert, or a proposed channel or system. AASHTO cautions, “Outfalls are the most downstream element in the storm drain system but should not be the last element to receive design attention” (Highway Drainage Guidelines, 4th Edition). The procedure for evaluating a storm sewer design begins at the outfall; therefore, consideration of outfall conditions is very important to storm sewer design. The following outfall conditions should be determined for each outfall before beginning storm sewer design:

- Outfall location. The discharge location may be into a receiving stream or an existing storm sewer system (open channel or closed conduit). Refer to Section 4A-4 for the Concept Plan. Consult with a drainage engineer before planning to discharge to an undefined swale, ditch, or stream.

- Outfall elevation. The storm sewer system outfall pipe flowline (also known as invert or inside bottom) elevation should not be below the receiving flowline elevation. For a receiving ditch or stream, the adjacent streambed flowline elevation should be evaluated for a determined distance (don't just use existing survey data at the existing outfall) so that elevations in scour (erosion) holes are not used.

See Design Velocity for additional design criteria.

Once outfall conditions have been determined, tailwater conditions and downstream erosion potential can be evaluated.

Tailwater Conditions

The design water surface elevation (design WSE) of the outfall is used in design to begin the HGL determination. The outfall design WSE must be estimated for the normal operating conditions of the storm sewer system and for alternate scenarios to assess risk of ponding or flooding potential. Determination of the design WSE and alternate scenarios requires knowledge of the outfall system watershed, storm sewer system watershed, and other factors and should be evaluated by someone knowledgeable in this design. Refer to AASHTO Highway Drainage Guidelines, 4th Edition, Chapter 9 for further consideration.

Downstream Erosion Potential and Runoff Reduction

HEC-14 notes, "Erosion at culvert outlets is a common condition. Determination of the local scour potential and channel erodibility should be standard procedure…" Discharge velocities are the main indicator of erosion potential and may be minimized by upstream storm sewer design considerations. Existing downstream erosion and/or flooding problems should be documented and evaluated.

Stormwater storage and/or energy dissipation may be required to protect an outfall, storm drain outlet, and/or downstream channel or property (including stream banks). Designers should evaluate existing concerns and other erosion indicators such as soil type, increase in discharge flow or volume over natural undeveloped discharges, etc.

HEC-14 discusses hydraulic design and energy dissipaters for culverts and channels. It also discusses flow transitions from pipe through flared end sections (aprons) and into channels. Chapter 5 of HEC-22 discusses stable channel design procedures and provides example problems for design and evaluation.

Refer to Section 4A-2 and Section 4A-4 for additional discussion on concept design considerations and documenting erosion potential and runoff reduction. Refer to SUDAS for erosion control and detention guidelines.

Hydraulic Grade Line (HGL)

The HGL is a line coinciding with the water level in the system. It is used to determine the acceptability of a design, see HGL under Design Criteria. Computer modeling is ideal for HGL checks. For hand calculation checks, refer to Chapter 7 of HEC-22 for step by step guidance on estimating the HGL and for design examples.

> **Note:** Ideally, the HGL throughout the storm sewer should maintain a smooth slope and stable velocity. Avoid abrupt jumps in the HGL.

Pressure Flow Design

Pressure flow design requires that the flow in the pipe be at a pressure greater than atmospheric pressure. Under this condition the water surface in the structures (intakes and manholes) is above the top of the pipes. The significant difference between pressure flow and open channel flow is that the pressure head will be above the top of the pipe and will not equal the depth of flow in the pipe. In this case, the pressure head rises to a level represented by the HGL.

The hydraulic gradient can be roughly estimated using the following formula:

$$\text{Hydraulic Gradient} = \frac{\text{elevation}_{upstream} - \text{elevation}_{downstream}}{\text{length}}$$

where:

$\text{elevation}_{upstream}$ = may be ground surface or top of pipe, ft

$\text{elevation}_{downstream}$ = generally the receiving stream or system WSE, ft

Length = length between above elevation locations, ft

The hydraulic gradient may be checked across several pipes and structures (length may include several pipes and structures). This evaluation may be used for rough evaluation of existing systems, concept designs and for rough design checks. Use computer modeling to evaluate the HGL of a system for final design purposes.

The following two example problems illustrate the hydraulic gradient design check.

Example 4A-10_4, Pressure Flow Problem 1

Example 4A-10_5, Pressure Flow Problem 2

Check for Major Storms

One of the last procedures in designing a storm sewer system is evaluation of and design for the major storm check. This generally includes design for the 100-year storm with consideration of overland flow paths for greater events. The major storm check is dominated by three concerns:

- Ponding depth on primary highways is not to exceed 1 foot.
- Residential dwellings and public, commercial, or industrial buildings are not to be inundated at the ground line unless they are flood-proofed.
- Water is not to accumulate in areas where it creates an unacceptable safety hazard for motorists or pedestrians.

To avoid these situations, drainage structures may need to be installed that do not correspond to the normal design recurrence interval.

When examining the system for a major storm event, determine how excess water will be stored and how it will reach the outlet (e.g. stream, river, lake). When excess water cannot get into the storm sewer system, the individual intakes – or possibly the entire storm sewer system – must be resized. Designers must consider all overland flow paths the water may take during the major design storm and greater design events. Flowage easements may be required to maintain overland flow paths and to prevent construction and building in overland flowage areas. Evaluation of major storms and the need for overland flowage easements requires careful analysis due to the potential impact on surrounding property.

Intake and Manhole Sizing

Once storm sewer pipes are sized, intake and manhole sizing can be finalized. Refer to the Standard Road Plans for intake and manhole dimensions.

The placement and type of manhole depends on:

- Location of traffic.
- Depth of manhole.
- Size of intercepting storm sewer pipe(s).
- Skew of intercepting storm sewer pipe(s).
- Other utilities.

Note: Scale drawings of pipes at structures will assist in evaluating structure dimensions (both vertically and horizontally).

Circular Structures

Precast manholes come in standard sizes. For each installation, a minimum diameter is required to maintain the structural integrity. The general rule is to keep a minimum of 6 inches between blockouts for adjacent pipes. To evaluate this, the blockout sizes of and angles between adjacent pipes are required. Refer to Table 1 for standard blockout dimensions.

Table 1: Manhole Blockout Sizes[1].

pipe diameter (inches)	manhole blockout (inches)
15	24
18	28
21	31
24	35
27	38
30	42
33	47
36	48
42	57
48	64
54	71
60	78
[1] Based on RCP.	

When two or more pipes are involved, adjacent pipes involving the most critical situation (the smallest angle and largest pipes) should be evaluated. If the critical situation is not apparent, then evaluate all situations involving adjacent pipes.

Rectangular Structures

Standard rectangular structures do not accommodate all pipe sizes. Larger pipe sizes may require intake modification.

Most intake and manhole standards provide guidance on maximum depths. Table 2 provides guidance for those which do not.

Table 2: Intake Maximum Depths.

intake type	maximum depth (ft)
SW-501	7
SW-505	7
SW-506	6.5
SW-511	7

Filling in Tabulation 104-5B

Use output from Geopak Drainage to fill out Tabulation 104-5B for the Plans.

When using letdown structures, calculate the exact length of pipe required for installation and adjust for elbows. Adjust flow lines accordingly. Round measurements to the next higher whole foot. If two types of pipe are used on the same structure, tabulate them on separate lines of the bid tabulation.

Design Documentation and Reporting

Storm sewer system documentation and reporting is discussed in Section 4A-2. Designers should also include an analysis of HGL results.

Chronology of Changes to Design Manual Section:

004A-010 Storm Sewer Design

6/25/2019 Revised

Updated hyperlinks.
Updated header logo and text.

2/9/2017 Revised

Removed metric units from the section.
Added reference to Section 1B-5 for pipe wall thicknesses.

9/13/2012 Revised

Updated minimum cover outside of pavement to match SUDAS.

7/29/2011 NEW

Rewritten material from old 4A-8. Removed example problem.