NORAD supported project in MRRD covering Capacity Building and Institutional Cooperation in the field of Hydrogeology for Faryab Province Afghanistan

Hydrogeology Course 1.4
Water Well Design

By Andreas de Jong
December 2013

NORPLAN 1

A girl stands in a almost dried-up well in Shuitang village, Weining county of Southwest China's Guizhou province on March 16, 2013. [Photo/Xinhua]

Source: http://www.chinadaily.com.cn/china/2013-03/17/content_16314251.htm

NORPLAN 2

PURPOSE OF THIS COURSE

The purpose of this course is to introduce:

1. Key theoretical issues to consider when designing water wells.
2. Illustrate theory with some practical examples of water well design.
3. Discuss key issues regarding water well design in Afghanistan.

NORPLAN 3

KEY REFERENCES

- ✓ Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.
- ✓ Water Wells and Boreholes; B. Misstear, D. Banks & L. Clark, 2006.
- ✓ Groundwater Hydrology, 3rd Edition; D.K. Todd & L.W. Mays, 2005.
- ✓ The Handbook of Groundwater Engineering, Editor: J. Delleur, 1999.
- ✓ Hydrogeology Field Manual, 2nd Edition; W. Weight, 2008.
- ✓ Minimum Construction Requirements for Water Bores in Australia; 3rd Edition, Feb 2012. Available online: http://adia.com.au/wp-content/pdf/MCR3RD2012B.pdf

NORPLAN 4

Tentative Course Schedule

Day	Date	Activity
1	Sunday 15.12.2013	Opening & Introduction Lecture: Introduction to Well Design Part 1 Practical: Well Design
2	Monday 16.12.2013	Lecture: Introduction to Well Design Part 2 Practical: Well Design
3	Tuesday 17.12.2013	Practical: Afghan Examples of Well Design
4	Wednesday 18.12.2013	Practical: Afghan Examples of Well Design

NORPLAN 5

TOPICS TO BE COVERED

1. Introduction
2. Drilling Methods
3. Casing & Screen Intervals & Well Depth
4. Casing & Screen Materials
5. Pump Type & Size
6. Casing Diameter
7. Gravel Pack Design
8. Screen Type & Slot Size
9. Well Completion
10. Well Development
11. Wellhead Design

NORPLAN 6

TOPICS TO BE COVERED

1. Introduction
2. Drilling Methods
3. Casing & Screen Intervals & Well Depth
4. Casing & Screen Materials
5. Pump Type & Size
6. Casing Diameter
7. Gravel Pack Design
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10. Well Development
11. Wellhead Design

NORPLAN 7

Definition of Water Well Design

Physical specifications of a well to meet the following criteria:

- ✓ Desired yield consistent with aquifer capability.
- ✓ Minimum drawdown.
- ✓ Good water quality, protected from contamination.
- ✓ Aquifer protection.
- ✓ Sediment-free yield.
- ✓ Long well life (minimum 25 years).
- ✓ Reasonable capital cost.
- ✓ Minimum maintenance cost.
- ✓ Compliance with national standards & regulations.

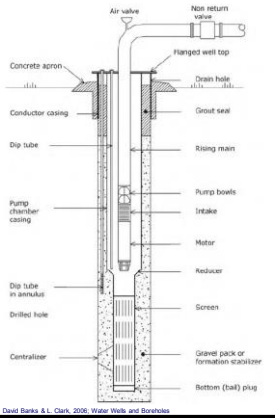
NORPLAN 8

Minimum Information Required for Well Design

- ✓ Geology & stratigraphy from samples & geophysical logs.
- ✓ Aquifer properties from pumping tests: tranmissivity, & storativity.
- ✓ Static water level & long term trends.
- ✓ Grain-size analysis of unconsolidated aquifers & identification of rocks & minerals.
- ✓ Water quality.

NORPLAN 9

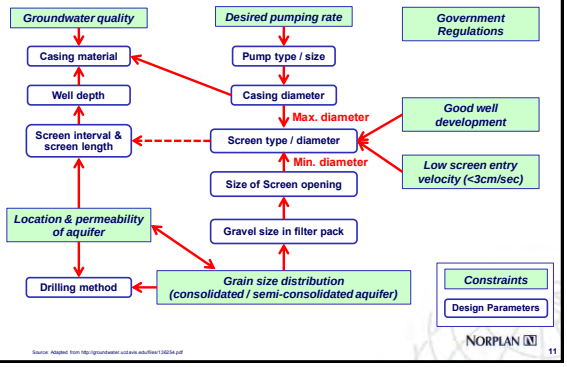
Standard Well Design



Source: B. Misstear, David Banks & L. Clark, 2006, Water Wells and Boreholes

NORPLAN 10

Decision Tree for Water Well Design



Source: Adapted from http://groundwater.ucdavis.edu/files/136254.pdf

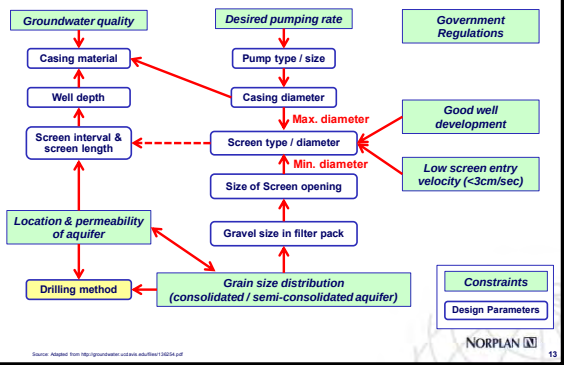
NORPLAN 11

TOPICS TO BE COVERED

1. Introduction
2. Drilling Methods
3. Casing & Screen Intervals & Well Depth
4. Casing & Screen Materials
5. Pump Type & Size
6. Casing Diameter
7. Gravel Pack Design
8. Screen Type & Slot Size
9. Well Completion
10. Well Development
11. Wellhead Design

NORPLAN 12

Decision Tree for Water Well Design

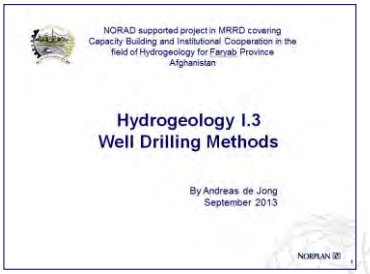


Source: Adapted from http://groundwater.ucdavis.edu/files/134254.pdf

NORPLAN 13

Drilling Methods & Well Depth

- ✓ Choice of drilling method depends on geology & availability of rigs / experienced drillers.
- ✓ See Course 1.3 Well Drilling Methods for details.



NORPLAN 14

TOPICS TO BE COVERED

1. Introduction
2. Drilling Methods
3. Casing & Screen Intervals & Well Depth
4. Casing & Screen Materials
5. Pump Type & Size
6. Casing Diameter
7. Gravel Pack Design
8. Screen Type & Slot Size
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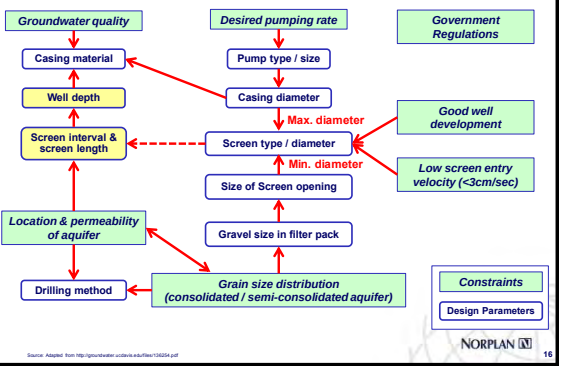
10. Well Development
11. Wellhead Design

NORPLAN 15

Decision Tree for Water Well Design

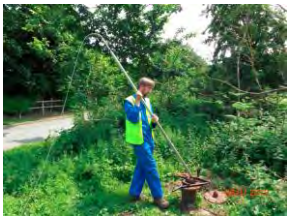


Source: Adapted from http://groundwater.ucdavis.edu/files/134254.pdf

NORPLAN 16

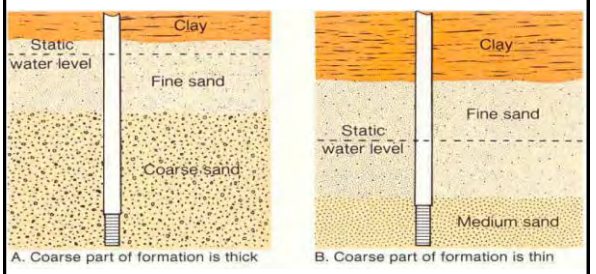
Casing & Screen Intervals (1)

- ✓ Well design based on geology (cuttings log) & geophysical logs (if available).
- ✓ Standard casing & screen lengths need to be respected (e.g. 6 metres).



NORPLAN 17

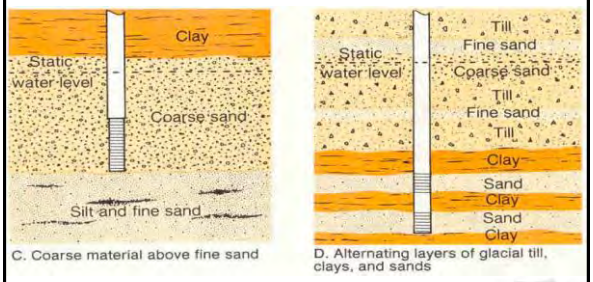
Casing & Screen Intervals (2)



Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sternett. Johnson Screens, 2007.

NORPLAN 18

Casing & Screen Intervals (3)



Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

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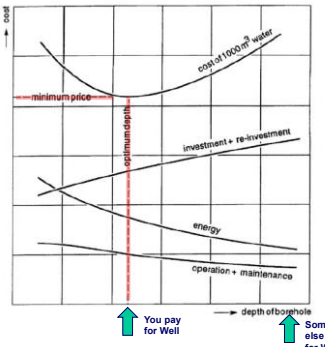
Well Depth Considerations – Cost



Costs of 1000 m3 water as a function of borehole depth.

Source: The Handbook of Groundwater Engineering. Editor: J. Delleur, 1999.

NORPLAN

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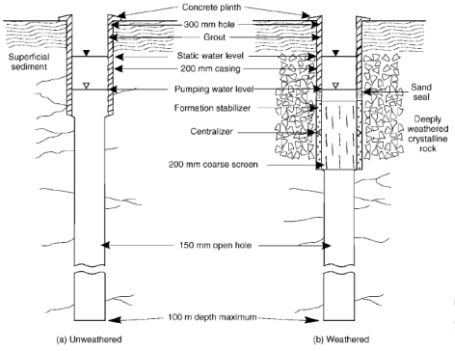
Well Design in Crystalline Aquifers



Source: B. Misstear, David Banks & L. Clark, 2006. Water Wells and Boreholes

NORPLAN

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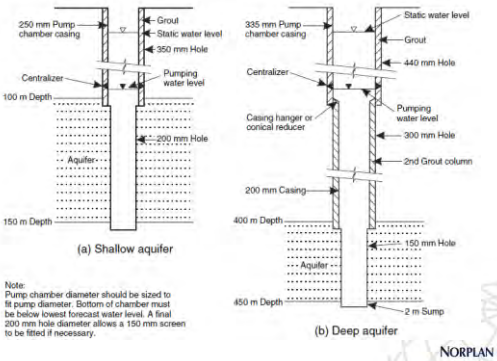
Well Design in Consolidated Aquifers



Note:
Pump chamber diameter should be sized to fit pump diameter. Bottom of chamber must be below lowest forecast water level. A final 200 mm hole diameter allows a 150 mm screen to be fitted if necessary.

Source: B. Misstear, David Banks & L. Clark, 2006. Water Wells and Boreholes

NORPLAN

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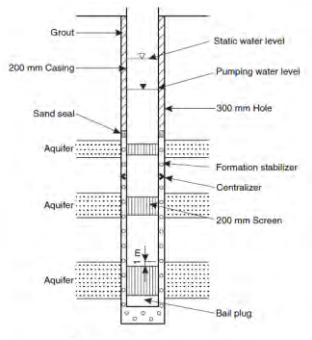

Note:
A variation on this design would be to have a larger diameter pump chamber, with a reducer connecting to the screen and casing string below.

Well Design in a Consolidated multiple aquifer system

Source: B. Misstear, David Banks & L. Clark, 2006. Water Wells and Boreholes

NORPLAN

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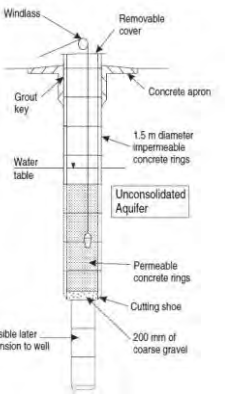
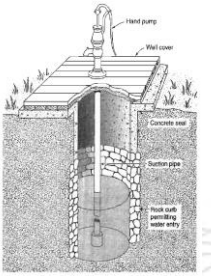


Hand-dug Well Design for a Shallow Water Table



Source: Groundwater Hydrology, 3rd Edition, D.K. Todd & L.W. Mays, 2005.

Source: B. Misstear, David Banks & L. Clark, 2006. Water Wells and Boreholes

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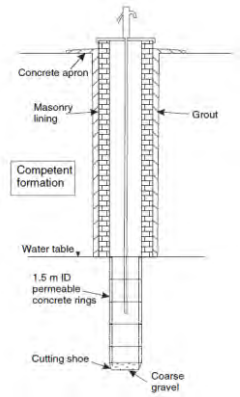
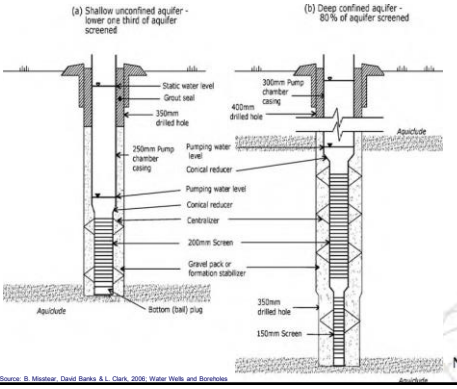
Hand-dug Well Design for a Deep Water Table



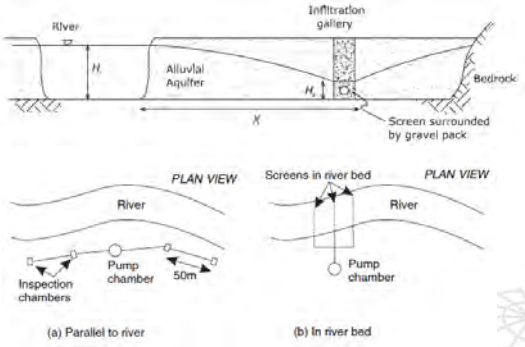
Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

Well Design in Unconsolidated Aquifers



Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

Infiltration Galleries



Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

Practical – Screen Intervals & Well Depth

TOPICS TO BE COVERED

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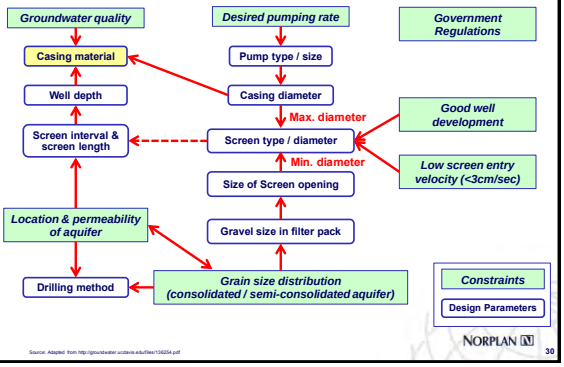
Decision Tree for Water Well Design



Source: Adapted from http://groundwater.ucdavis.edu/files/106254.pdf

Casing & Screen Materials – Key Considerations

1. Corrosion & Incrustation.
2. Bacteria.
3. Water temperature.
4. Drilling Method.
5. Collapse Strength.
6. Tensile Strength.
7. Column Strength.

Indicators for Corrosive Groundwater

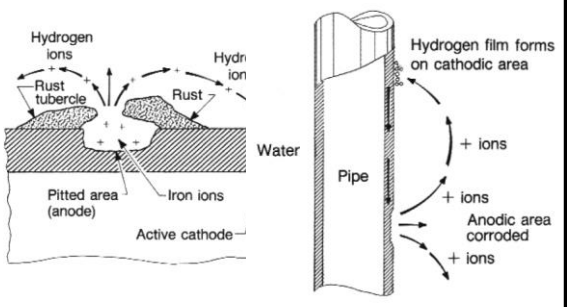
Groundwater can be corrosive if it has some of the following characteristics:

- Low pH
- Dissolved oxygen (DO) > 2ppm
- Hydrogen sulphide (H2S) > 1ppm
- Total Dissolved Solids (TDS) > 1,000ppm
- Carbon dioxide (CO2) > 50ppm
- Chloride (Cl) > 200ppm

The rate of corrosion doubles for every 10°C increase in temperature.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Corrosion of Iron at Anodic Areas



Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Corrosion from H_2S & CO_2

Source: http://www.ifa.noten/file/departments/materials_and_corrosion_tech/projects/ktoc

Casing Material for Corrosive Groundwater

- Type 304 stainless steel
- Type 316 & 316L stainless steel
- Nickel-chromium alloy, Inconel
- Nickel-copper alloy, Monel
- Nickel-molebdenium alloy, Hastelloy A, B & C
- etc

or

- Thermoplastic screens

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Indicators for Incrusting Groundwater

Groundwater can be incrusting if it has some of the following characteristics:

- High pH > 7.5
- Carbonate hardness > 300ppm
- Iron > 0.5ppm
- Manganese > 0.2ppm

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Casing Material for Incrusting Groundwater

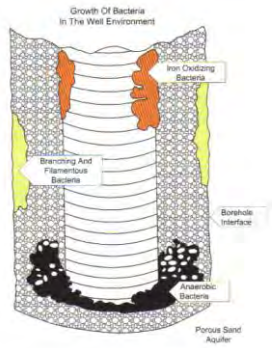
Must be able to resist frequent acid treatment:

- Stainless steel is better than mild steel
- PVC OK, but check specifications.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Microbial Induced Corrosion



Main bacterial groups:

- Slime Formers
- Iron Oxidisers
- Anaerobes e.g. sulphate reducing bacteria (SBR)

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

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Managing Bacteria

- Seal off nutrient rich aquifers.
- Do not allow water to cascade into the well.
- Good wellhead design to allow access for maintenance.
- Minimize annular thickness of borehole..
- Maximize open area of screen.
- Use short or no well sump.
- Minimize low flow zones by strategic pump & screen placement.
- Do not use polyphosphates (food source for bacteria) to remove clays/bentonite during well development.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

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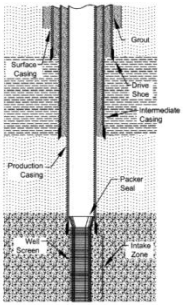
Selection of Casing Material



- ✓ Appropriate for application loads & stresses during installation.
- ✓ Theoretical safety margin of 1.5 to 2.0

Take into consideration:

- Water quality
- Planned well depth
- Well diameter
- Drilling methods
- Material costs
- Compliance with regulations.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Well Casing Material Properties

		Carbon Steel	Stainless Steel	PVC	Fiberglass
Specific Gravity		7.8	8	1.4	1.9
Yield Strength	psi	35,000	30,000	7,000	12,000
	Mpa	240	210	50	80
Axial Modulus	psi	30,000,000	28,000,000	400,000	2,000,000
	Mpa	206,900	193,100	2,800	13,800
Poissons Ratio		0.28	0.3	0.4	0.6
Service Temperature	°F	< 1,000	< 1,000	< 140	< 300
	°C	< 538	< 538	< 60	< 149
Coefficient of Thermal Expansion	in/in °F	6.60E-05	1.01E-04	2.95E-05	1.00E-05
	cm/m °C	1.19E-04	1.82E-04	5.40E-05	1.80E-05
Water Absorption	wt % per 24 hr	Nil	Nil	0.05	0.2

(PVC data from Harvel Plastics Engineering Manual.
Fiberglass data from Centron Fiberglass Pipe Products literature.)

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Selection of Casing Material

Corrosive Groundwater	PVC or Stainless steel
Casing is driven/pulled	Steel

Metal	Composition		Suggested Applications
Low-Carbon Steel	Carbon	0.8% max	Not corrosion resistant. Satisfactory life in noncorrosive, nonincrusting waters.
	Iron	Balance	
200 Series Stainless Steel	Chromium	16.5% max	Corrosion resistance similar to Type 304. Non-magnetic, greater tensile than Type 304.
	Manganese	9% max	
	Nickel	4% max	
	Carbon	0.15% max	
	Iron	Balance	
Type 304 Stainless Steel	Chromium	18% min	Excellent corrosion resistance. Type of stainless steel widely used in water-well construction.
	Nickel	8% min	
	Manganese	2% max	
	Carbon	0.08% max	
	Iron	Balance	
Type 316L Stainless Steel	Chromium	16% min	Used in moderate saline groundwater. Molybdenum resists pitting/crevice corrosion in moderate saline water. Better resistance to stress-corrosion cracking than Type 304.
	Nickel	10% min	
	Molybdenum	2% min	
	Carbon	0.03% max	
	Iron	Balance	
Carpenter® 20Cb-3	Nickel	32% min	Strong resistance to stress-corrosion cracking, pitting, and crevice corrosion. Satisfactory in high-saline water and at temperatures greater than 100°F (38°C).
	Chromium	19% min	
	Copper	3% min	
	Molybdenum	2% max	
	Carbon	0.03% max	
	Iron	Balance	

Metal	Composition		Suggested Applications
Monel® 400	Nickel (plus Cobalt)	63% min	Satisfactory in sea water (high sodium chloride with dissolved oxygen). Is sensitive to hydrogen sulfide.
	Copper	28% min	
	Iron	2.5% max	
	Manganese	2% max	
Incoloy® 825	Nickel (plus cobalt)	38% min	Low corrosion potential in high-chloride water, resists cracking, pitting, and crevice corrosion. Used for geo-thermal, oil, and gas-injection wells.
	Iron	22% min	
	Chromium	19.5% min	
	Molybdenum	2.5% min	
	Copper	1.5% min	
Inconel® 600	Nickel (plus cobalt)	72% min	For use in geothermal, oil and gas, and injection-well applications. Strong resistance to stress-corrosion cracking.
	Chromium	14% min	
	Iron	6–10%	
Hastelloy® C	Nickel	51% min	Extremely corrosion-resistant alloy. Used in aggressive environments (brine, corrosive gases), and where temperatures exceed 200°F (93°C). For use in geothermal, oil and gas, and injection wells.
	Molybdenum	15% min	
	Chromium	14.5% min	
	Iron	4% min	
	Tungsten	3% min	
	Cobalt	2.5% max	
	Vanadium	0.35% max	

Polyvinyl Chloride (PVC)

- ✓ Corrosion resistant
- ✓ Light weight
- ✓ Low cost
- ✓ Easy installation
- ✓ Resistance to acid treatment.
- ✓ Non bio-degradable
- ✓ Collapse resistance same for all pipe sizes for a particular standard

Drawbacks:

- Low impact strength
- Not suitable at high temperatures.
- Degrades in UV light (sunshine)
- Brittle at low temperatures

Polyvinyl chloride (PVC) & Chlorinated PVC Physical Properties at 23°C

Property	ASTM Test Method	PVC Cell Class 12454 (ASTM D1784)	CPVC Cell Class 23447 (ASTM D1784)
Specific Gravity	D-792	1.40 +/- 0.02	1.52 +/- 0.02
Tensile strength (psi)	D-638	7,450	7,320
Tensile Modulus of Elasticity (psi)	D-638	420,000	360,000
Poisson's Ratio		0.410	0.386
Compressive Strength (psi)	D-695	9,600	10,000
Impact Strength, Izod Method, Notched (ft-lb/in)	D-256	0.75	2.0
Deflection Temperature (°F) Under Load (264 psi)	D-648	170	226
Coefficient of Linear Expansion (in/in °F)	D-696	2.9×10^{-5}	3.4×10^{-5}
(Harvel Plastics, Inc.)			

Fiberglass-Reinforced Plastic (FRP)

- ✓ Corrosion resistant
- ✓ Non-conductive
- ✓ Light weight
- ✓ Very strong

Drawbacks:

- Heat reduces collapse strength
- Permeability can allow contaminants into well
- Joining sections needs expertise & difficult to ensure that is it watertight.
- Health risks from fiberglass if casing is damaged.

Polyester Resin-Based Fiberglass Physical properties

Pipe Size (in)	Nom OD (in)	Wall (in)	Internal Pressure (psi)	Collapse (psi)	Tensile (lb)	Wt/Ft (lb)	Coupling Diameter (in)
4.5	5.25	0.375	575	3,380	21,750	4.4	7.5
6.5	7.25	0.375	400	1,280	30,975	6.3	9.5
8.5	9.25	0.375	300	615	39,975	8.3	11.5
10.5	11.25	0.375	250	340	49,000	10.2	13.5
12	12.75	0.375	225	230	55,750	11.6	15.0
14	14.75	0.375	200	150	64,750	13.5	17.0
16	16.75	0.375	175	115	73,750	15.4	19.25
All values are approximate (Burgess Well Co.).							

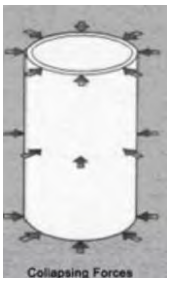
Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 49

Practical – Corrosive & Incrusting Water

NORPLAN 50

Casing Strength Requirements: Collapse Strength



Source: http://www.roscoemoss.com/tech_manuals/gwwc/images/picture19.jpg

Radial casing collapse due to:

- **Fixed Forces**
  - formation weight
  - water column
- **Dynamic Stresses**
  - Caving
  - Filter pack movement
  - Subsidence
  - Earthquakes

NORPLAN 51

Collapse Strength of Casing Materials

Table 4.3 Typical collapse strengths of selected casing materials[a]

Material	Casing wall thickness (mm)	Collapse strength (kPa)
Steel casing	7.9	5245
PVC[b]	13[c]	790
ABS[b]	13[c]	690
Fibreglass	6.0	690

[a]Collapse strengths are for 250 mm nominal diameter casings.
[b]Collapse strengths are for room temperature, and reduce at higher temperatures (see text).
[c]These are approximate wall thicknesses for SDR 21 casing (see text for explanation of SDR).
Sources: Clark (1988), American Water Works Association (1998), National Ground Water Association (1998).

Source: B. Misstear, David Banks & L. Clark, 2006. Water Wells and Boreholes

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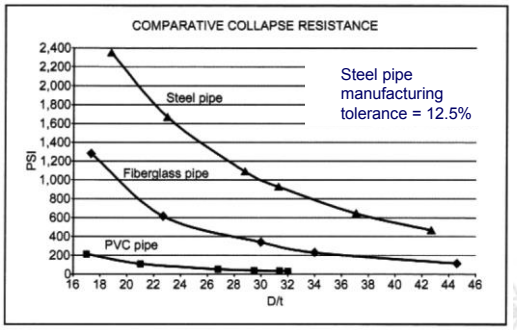
Steel Pipe – Common Collapse Ratings (PSI)



Steel pipe manufacturing tolerance = 12.5%

D = diameter, t = thickness

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 53

Steel Pipe – Effect of Wall Thickness Tolerance

Pipe OD		Standard Wall				Change
in	cm	Thickness (in)	Thickness (cm)	Collapse (psi)	Collapse (kPa)	Reduction in Collapse
8.625	21.9	0.25	0.64	752	5,184	-26%
12.75	32.4	0.3125	0.79	518	3,571	-27%
16	40.6	0.375	0.95	467	3,219	-27%

Pipe OD		Standard Wall Minus 12.5%				Change
in	cm	Thickness (in)	Thickness (cm)	Collapse (psi)	Collapse (kPa)	Reduction in Collapse
8.625	21.9	0.2188	0.56	560	3,861	-26%
12.75	32.4	0.2734	0.69	378	2,606	-27%
16	40.6	0.3281	0.833	339	2,337	-27%

Allow a 25% safety margin for manufacturing tolerances

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 54

Design Criteria – Collapse Strength

- ✓ Check manufacturing tolerances
- ✓ Check pressure differentials
- ✓ Apply a safety factor of 1.5
- ✓ If overlying formation weight is not self-supporting, assume a pressure of 23 kPa/m.
- ✓ Hydrostatic pressure due to fresh water is 9.8 kPa/m.

$$P = h \times 9.77\ kPa/m$$

P = fluid pressure at depth (kPa)
h = height of static fluid from bottom of well

Design Criteria – Collapse Strength

- ✓ Hydrostatic pressure is offset if water levels inside & outside the well are equal.
- ✓ Calculate the pressure differential across the casing using the formula:

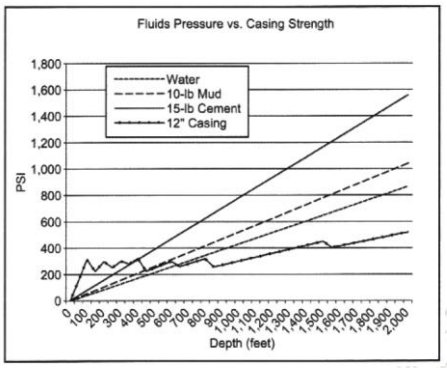
$$\Delta P = (H - h) \times 9.77\ kPa/m \times \left({}^{\rho_0}/_{\rho_w}\right)$$

ΔP = pressure differential exerted on the casing (kPa)
H = height of fluid outside the casing from total depth (m)
h = height of static fluid from bottom of well
ρ_0 = fluid density outside the casing
ρ_w = 1.0 kg/L = density of fresh water (kPa/m)

Minimum psi/ft (kPa/m) for Carbon Steel Casing

Depth ft (m)	8 in (203 mm)	10 in (254 mm)	12 in (305 mm)	14 in (356 mm)	16 in (406 mm)	18 in (457 mm)	20 in (508 mm)	24 in (610 mm)
0–100 (0–30)	7.6 (25.2)	4.6 (14.9)	3.1 (10.2)	2.4 (8.1)	1.7 (5.7)	1.3 (4.2)	1.0 (3.2)	1.1 (3.6)
100–200 (30–61)	3.8 (12.4)	2.3 (7.6)	1.5 (5.0)	1.2 (4.0)	0.9 (2.8)	0.6 (2.1)	0.5 (1.6)	0.5 (1.8)
200–300 (61–91)	2.5 (8.3)	1.5 (5.1)	1.0 (3.4)	0.8 (2.7)	0.6 (1.9)	0.8 (2.5)	0.6 (1.9)	0.4 (1.2)
300–400 (91–122)	1.9 (6.2)	1.2 (3.8)	0.8 (2.5)	0.6 (2.0)	0.8 (2.5)	0.6 (1.9)	0.4 (1.4)	0.4 (1.4)
400–600 (122–183)	1.3 (4.1)	0.8 (2.5)	0.5 (1.7)	0.4 (1.3)	0.5 (1.7)	0.4 (1.2)	0.3 (0.9)	0.3 (0.9)
600–800 (183–244)	0.9 (3.1)	0.6 (1.9)	0.4 (1.3)	0.5 (1.7)	0.4 (1.2)	0.28 (0.9)	0.3 (1.1)	0.21 (0.7)
800–1,000 (244–305)	0.8 (2.5)	0.5 (1.5)	0.3 (1.0)	0.4 (1.4)	0.3 (1.0)	0.23 (0.7)	0.27 (0.9)	0.25 (0.8)
1,000–1,500 (305–457)	0.5 (1.7)	0.5 (1.7)	0.3 (1.1)	0.28 (0.9)	0.3 (1.0)	0.24 (0.8)	0.18 (0.6)	NA
1,500–2,000 (457–610)	0.4 (1.2)	0.4 (1.2)	0.26 (0.9)	0.21 (0.7)	0.24 (0.8)	0.18 (0.6)	0.20 (0.7)	NA

Comparative Collapse Resistance



Practical – Collapse Strength

Casing Strength Requirements: Tensile Strength

Axial tension loads imparted on casing string during installation come from:

1. Weight of casing & screen.
2. Drag forces transferred to string assembly during gravel packing.

Source: http://www.roscoemoss.com/tech_manuals/gwwc/images/picture19.jpg

Tensile Strength of Casing Materials

Table 4.4 *Tensile strengths of selected casings*

Material	Specific gravity	Tensile strength (MPa)
Low-carbon steel	7.85	414
Stainless steel (Type 304)	8.0	552
PVC	1.4	55
ABS	1.04	31
Fibreglass	1.89	115

The strength of plastic casings reduces at high temperatures (see text).
Source: based on data from Driscoll (1986) and Purdin (1980).

Design Criteria – Tensile Strength (1)

- ✓ Calculate the weight of the casing assembly using:

$$Wt = [k \times t(D - t)] \times L$$

Wt = total weight of casing (lb or kg)
t = wall thickness of pipe (in or cm)
D = outside diameter of pipe (in or cm)
L = total length of pipe (ft or m)

	LCS	SS	PVC	Fiberglass	
$k =$	10.68	10.78	2.1	2.7	U.S. customary
	0.229	0.231	0.15	0.62	SI

Design Criteria – Tensile Strength (2)

- ✓ Calculate the casing tensile strength using:

$$Cts = \frac{\pi \times t \times S_t \times (D_0 - t)}{2000}$$

Cts = casing tensile strength(tons or kg)
D_0 = casing outside diameter (in or mm)
S_t = ultimate tensile strength of material (LCS = 70,000psi or 413.7 MPa)
t = casing wall thickness (in or mm)

Design Criteria – Tensile Strength (3)

- ✓ Calculate the buoyancy factor using:

$$B = \frac{(Dm - Df)}{Dm}$$

B = buoyancy factor (dimensionless)
Dm = density of casing material (lb/ft^3 or kg/m^3)
Df = density of fluid (lb/ft^3 or kg/m^3)

Design Criteria – Tensile Strength (4)

- ✓ Calculate the hook load using:

$$HL = SWd + SWw$$

HL = hook load (lb or kg)
SWd = dry string weight (lb or kg)
SWw = wet string weight (lb or kg)

Design Criteria – Tensile Strength (5)

- ✓ The buoyancy effect is minimal for steel casing and can be ignored.
- ✓ Design loads should be calculated using the full air-weight of the casing (actual weight will be less due to buoyancy effect).
- ✓ Use a safety factor for tensile strength of 1.5 to 2.0.

Practical – Tensile Strength

Casing Strength Requirements: Column Strength

- The casing will buckle if the downward compressive force on the casing assembly exceeds the yield strength of the material.
- Casing & screen assembly should be suspended in the borehole before gravel packing & cementation.
- Always drill the borehole deeper than required in case there is some cave in.

Source: http://www.roscoemoss.com/tech_manuals/gwwc/images/picture19.jpg

Design Criteria – Column Strength (1)

✓ Calculate the column strength using:

$$Cas = \frac{\pi \times t \times S_{yp} \times (D_0 - t)}{2000}$$

Cas = casing axial compression strength (tons or kg)
S_{yp} = material yield strength
(LCS = 35,000psi or 241.3 MPa)
D_0 = casing outside diameter (in or mm)
t = casing wall thickness (in or mm)

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Joining Steel Casing

- Welding:
  - Be careful to avoid burn-through (metal deposited on inside of casing)
  - Electrode selection is important when joining different metals.
- Steel casing threads:
  - Check strength of couplings

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Minimum Joint Strength – Standard Threaded Line Pipe

Nom Size (in)	OD (in)	Wall (in)	Threads (per in)	Engaged Thread (in)	Joint Strength Grade (lb)	
					A	B
4	4.500	0.237	8	1.094	61,900	74,500
5	5.563	0.280	8	1.187	79,200	95,100
6	6.625	0.280	8	1.208	95,800	115,000
8	8.625	0.277	8	1.313	107,000	128,000
8	8.625	0.322	8	1.313	133,000	159,000
10	10.750	0.279	8	1.460	122,000	146,000
10	10.750	0.307	8	1.460	141,000	168,000
10	10.750	0.365	8	1.460	178,000	213,000
12	12.750	0.330	8	1.610	173,000	206,000
12	12.750	0.375	8	1.610	205,000	244,000
14	14.000	0.375	8	1.812	226,000	283,000
16	16.000	0.375	8	2.062	253,000	301,000
18	18.000	0.375	8	2.250	376,000	328,000
20	20.000	0.375	8	2.375	294,000	349,000
Strength basis is pullout (ARMCO Tubulars Division).						

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Joining Plastic Casing

- Solvent Welding (using solvent cement)
  - Clean pipe & coupling surfaces using primer.
  - Apply solvent uniformly.
  - Join & allow sufficient curing time.
  - Use low-temperature solvent cement below 4.4°C
  - Use special solvent to join PVC & ABS casing.
  - The joint will be equal or stronger than casing if work is done properly.
- Threaded connections:
  - Use in water quality monitoring wells where solvents are not allowed.
  - Use special joints for temperatures above 43°C.
  - Use special thread lubricants & sealants.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Joining Fibreglass Casing

- Threaded joints are most common, as epoxy or polyester-resin cement takes a long time to set.
- Slip joints
- Pin & Box ends
- Threaded adaptors between fibreglass & metallic screens.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Practical – Column Strength

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TOPICS TO BE COVERED

1. Introduction
2. Drilling Methods
3. Casing & Screen Intervals & Well Depth
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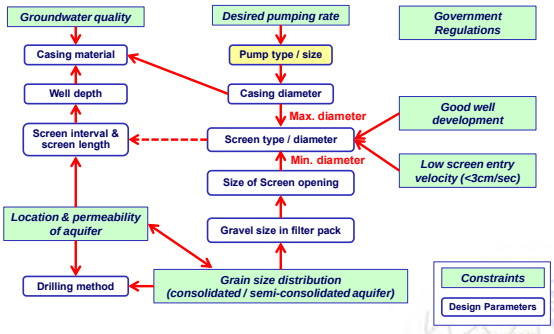
8. Screen Type & Slot Size
9. Well Completion
10. Well Development
11. Wellhead Design

NORPLAN

Decision Tree for Water Well Design



Source: Adapted from http://groundwater.ucdavis.edu/files/134254.pdf

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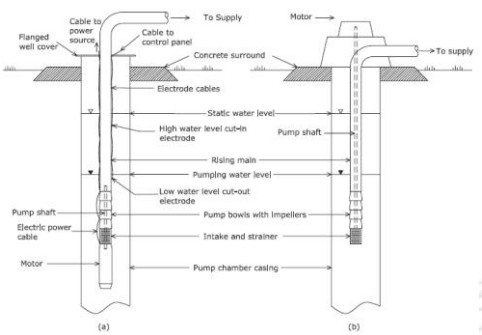
Pumps



electrical submersible pump

vertical turbine pump

Source: B. Misstear, David Banks & L. Clark, 2006. Water Wells and Boreholes

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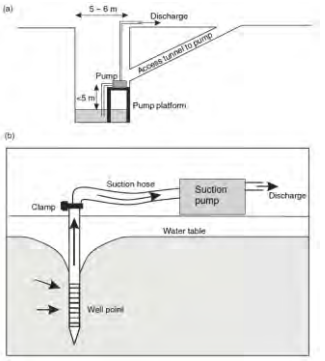
Suction Pumps



Source: B. Misstear, David Banks & L. Clark, 2006. Water Wells and Boreholes

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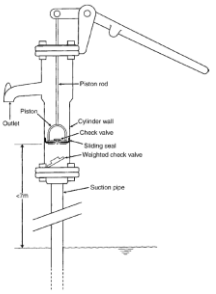
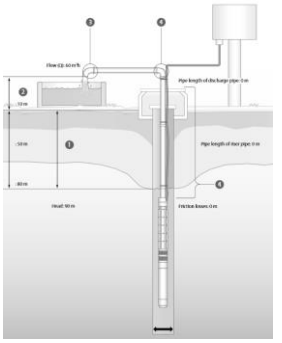
Hand Pumps



Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

NORPLAN

Selecting the Correct Pump

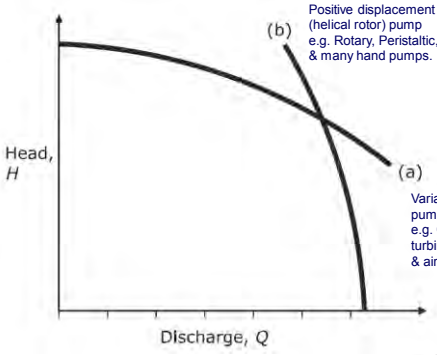


Total Head Required =
Dynamic water table (1)
+ Lift above ground (2)
+ Discharge pressure (3)
+ Losses in pipes, valve and bends (4)

Source: GRUNDFOS SP ENGINEERING MANUAL

NORPLAN

Typical Pump Curves



Positive displacement (helical rotor) pump
e.g. Rotary, Peristaltic, Piston & many hand pumps.

Variable displacement pump
e.g. Centrifugal (vertical turbine & submersible turbin & airlift pumps.

Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

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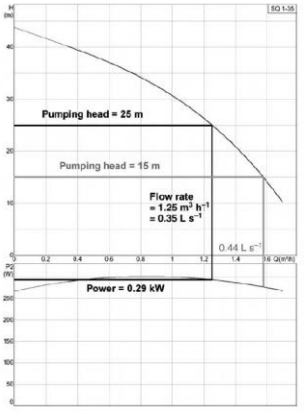

Example Pump Curve for Grundfos SQ 1-35 3" Submersible Pump

Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

NORPLAN

Practical – Pump Selection

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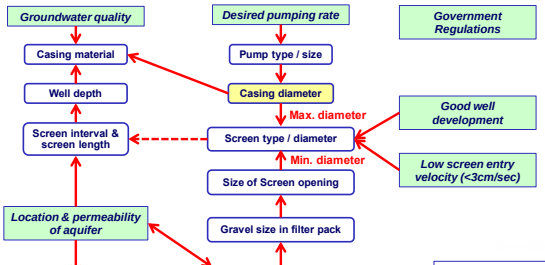
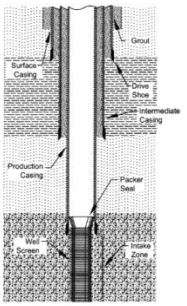
NORPLAN

Decision Tree for Water Well Design



Source: Adapted from http://groundwater.ucdavis.edu/files/134234.pdf

Well Casing

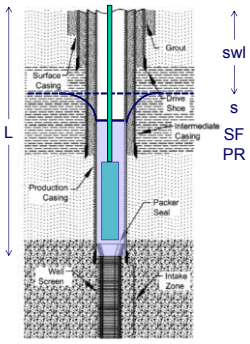


- ✓ Houses the pump
- ✓ Draws water from aquifer to pump
- ✓ Protects aquifer from contamination.

1. Surface casing (Conductor Casing)
2. Production casing

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Design Criteria – Length of Upper Well Casing



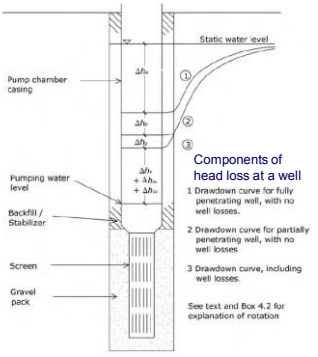
Where the pump will be housed in the upper well casing, the minimum required length of casing is:

$$L = swl + s + SF + PR$$

swl = static water level
s = anticipated drawdown
SF = Safety factor
PR = Pump requirements

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Well Depth Considerations



Source: B. Misstear, David Banks & L. Clark, 2006. Water Wells and Boreholes

Practical – Length of Upper Well Casing

Pipe Sizes

- Actual pipe size = outer diameter (OD) & inner diameter (ID) varies with pipe diameter and wall thickness.
- "Nominal" means inside diameter e.g. 6-inch (152mm) nominal
  OD = 6.625" (168mm)
  ID = 6.065" (154mm)
- Pipes > 12" is designated by the outside diameter.
- ASTM standards or API standards

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Design Criteria – Casing Diameter

- Large enough to allow installation & safe operation of the pump.
- Large enough to reduce uphole velocity to < 5ft/sec (1.5 m/sec) to minimize head losses.
- The pump size determines the casing size. The casing should be at least one and preferably two pipe sizes larger than the nominal pump diameter.
- Check submersible pump specifications for motor cooling flow rate requirements.

Source: GRUNDFOS SP ENGINEERING MANUAL

Well Diameters & Pumping Rates

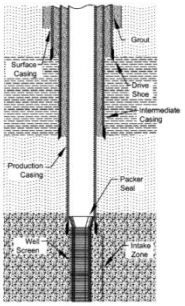
Anticipated Well Yield		Nominal Size of Pump Bowls		Optimum Size of Well Casing†		Smallest Size of Well Casing†	
m^3/day	GPM	mm	in	mm	in	mm	in
< 545	< 100	102	4	152 ID	6 ID	127 ID	5 ID
409 to 954	75 to 175	127	5	203 ID	8 ID	152 ID	6 ID
818 to 1,910	150 to 350	152	6	254 ID	10 ID	203 ID	8 ID
1,640 to 3,820	300 to 700	203	8	305 ID	12 ID	254 ID	10 ID
2,730 to 5,450	500 to 1,000	254	10	356 OD	14 OD	305 ID	12 ID
4,360 to 9,810	800 to 1,800	305	12	406 OD	16 OD	356 OD	14 OD
6,540 to 16,400	1,200 to 3,000	356	14	508 OD	20 OD	406 OD	16 OD
10,900 to 20,700	2,000 to 3,800	406	16	610 OD	24 OD	508 OD	20 OD
16,400 to 32,700	3,000 to 6,000	508	20	762 OD	30 OD	610 OD	24 OD

* For specific pump information, the well-designer should contact a pump supplier, and provide the anticipated yield, the head conditions, and the required pump efficiency.

† The size of the well casing is based on the greater outside diameter (OD) of the pump bowls or, for submersible pumps, the pump and motor. Although done, it is not good practice to place the pump bowls (or submersible) in the screen area, particularly in high-capacity wells.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Telescoping Casing



- Conductor (surface casing) set to stabilize ground surface.
- Production casing cemented to protect well from surface contaminants.
- Production casing can be telescoped.
- Screens below the pump intake can be of smaller diameter, provided that the uphole velocity <1.5m/sec.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Maximum Discharge Rates & Diameters Based on 1.5m/sec uphole velocity

Nominal Casing Size		Maximum Discharge	
in	mm	gpm	ℓ/sec
4	102	200	12.6
5	127	310	19.6
6	152	450	28.4
8	203	780	49.2
10	254	1,230	77.5
12	305	1,760	111
14	356	2,150	135
16	406	2,850	179
18	457	3,640	229
20	508	4,540	286
24	609	6,620	418

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

TOPICS TO BE COVERED

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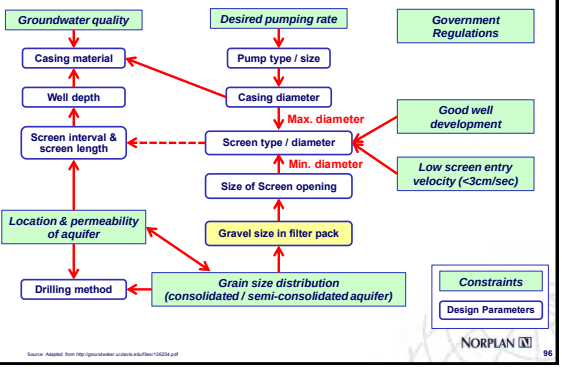
5. Pump Type & Size
6. Casing Diameter
7. Gravel Pack Design
8. Screen Type & Slot Size
9. Well Completion
10. Well Development
11. Wellhead Design

Decision Tree for Water Well Design



Source: Adapted from http://groundwater.ucdavis.edu/files/136254.pdf

Design Criteria – Type of Gravel Pack (1)

- ✓ Identify aquifer layers to be screened.
- ✓ Obtain representative samples of the formations.
- ✓ Carry out grain size analysis of each layer.
- ✓ Plot grain-size distribution curves.
- ✓ Use the layer with the finest material for the screen & filter pack design.
- ✓ Calculate the Uniformity Coefficient, UC

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

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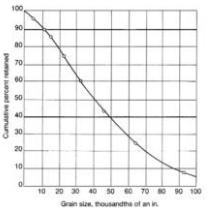
Uniformity Coefficient – % Retained Formula

$$UC = \frac{D_{40}}{D_{90}}$$

UC = Uniformity Coefficient
D_{40} = Diameter of 40% of the retained size of the sediment
D_{90} = Diameter of 90% of the retained size of the sediment



Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

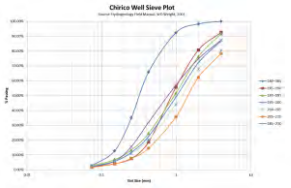
NORPLAN

98

Uniformity Coefficient – % Passing Formula

$$UC = \frac{D_{60}}{D_{10}}$$

UC = Uniformity Coefficient
D_{60} = Diameter of 60% finer than size of the sediment.
D_{10} = Diameter of 10% finer than size of the sediment.



NORPLAN

99

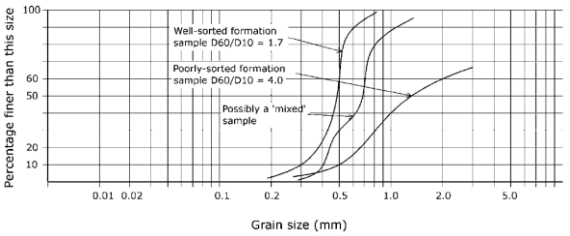
Sieve Analysis (1)

Source: MDW

NORPLAN

100

Sieve Analysis (2)



Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

NORPLAN

101

Practical – Sieve Analysis Interpretation

NORPLAN

102

Design Criteria – Type of Gravel Pack (2)

- ✓ Is the aquifer poorly sorted?
  Uniformity Coefficient, UC > 3
  Use a natural gravel pack.
- ✓ Is the aquifer well sorted?
  Uniformity Coefficient, UC < 3
  Effective Grain Size, D10 < 0.25 mm.
  Use an artificial gravel pack

$$UC = \frac{D_{60}}{D_{10}}$$

Source: Adapted from Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 103

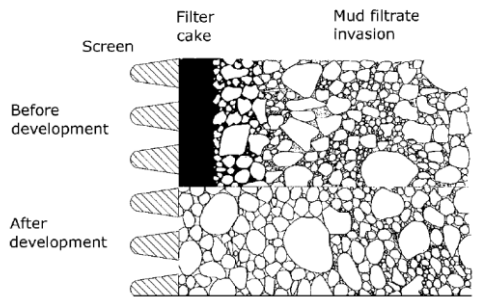
Natural Gravel Pack

- ✓ Fines are removed from the aquifer near the well, and no artificial gravel pack is required.
- ✓ Suitable for non-homogeneous sediments.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

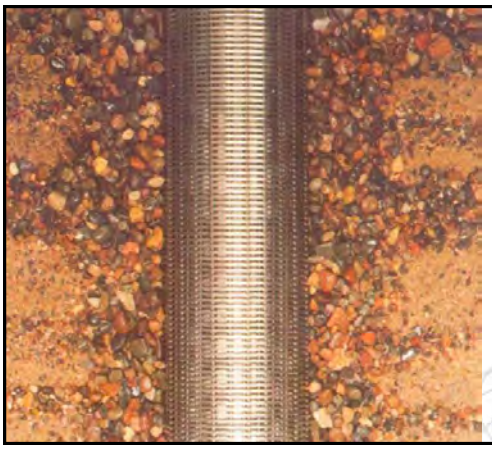
NORPLAN 104

Development of a Natural Gravel Pack



Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

NORPLAN 105



NORPLAN 106

Design Criteria – Natural Gravel Pack

- ✓ Slot size should retain 40% of the aquifer material & let 60% pass. Where samples are unreliable retain 50%.
- ✓ Retain 50% aquifer material when:
  - Groundwater is corrosive and you are using low-carbon steel.
  - In calcareous formations which will be developed with acid.
  - In thin aquifers overlain by fine material.
  - If there is little time for development.
  - In well sorted formations.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 107

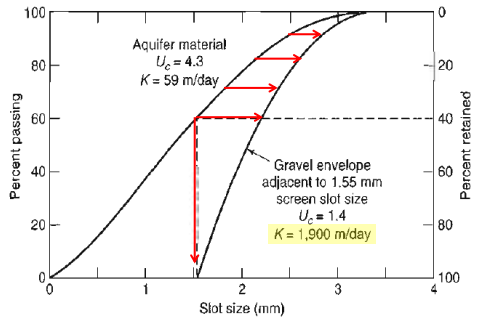
Design Criteria – Natural Gravel Pack

- ✓ Retain 30 – 50% of aquifer material when:
  - In coarse sand and gravel aquifers.
  - When extra development time is not an issue.
  - In incrusting groundwater conditions. This will increase the service life of the well.

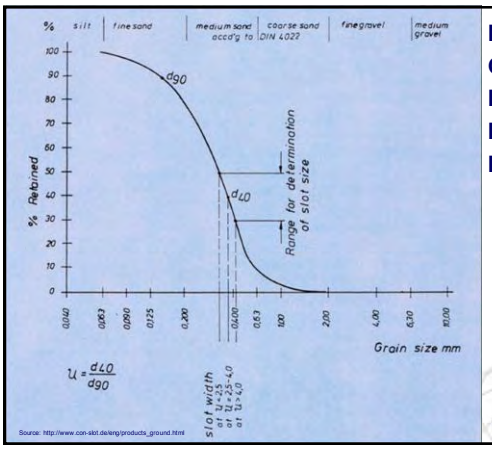
Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 108

Natural Gravel Pack – Improvement in K



Source: Groundwater Hydrology, 3rd Edition: D.K. Todd & L.W. Mays, 2005.



Source: http://www.con-slot.de/eng/products_ground.html

Natural Gravel Pack Design DIN4924

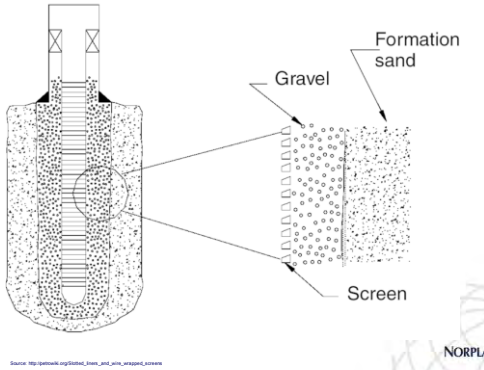
Practical – Natural Gravel Pack Design

Artificial Gravel Pack

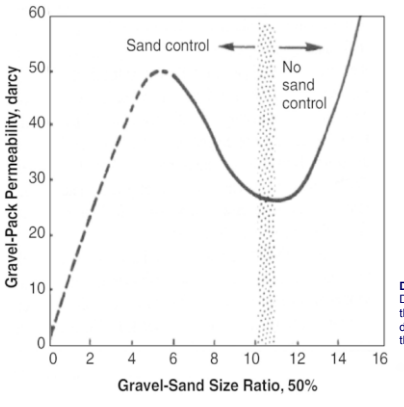
- ✓ Zone between well screen and aquifer is replaced by an artificial gravel pack.
- ✓ Allows faster well development.
- ✓ Suitable for screens with low open area, where well development is not very efficient.
- ✓ Suitable for homogeneous aquifers, and fine grained aquifers.
- ✓ Suitable where a very small slot size would otherwise be needed for a natural gravel pack.
- ✓ Suitable where groundwater is very incrusting.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sternett. Johnson Screens, 2007.

Artificial Gravel Pack



Source: http://petrowiki.org/Slotted_liners_and_wire_wrapped_screens

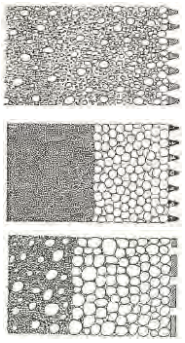


Effect of gravel-sand ratio on sand control permeability

D_{50} / d_{50}
D_{50}: Median grain size of the gravel-pack sand.
d_{50}: Median grain size of the formation sand.

Source: http://petrowiki.org/Gravel_pack_design#cite_note-r2-1

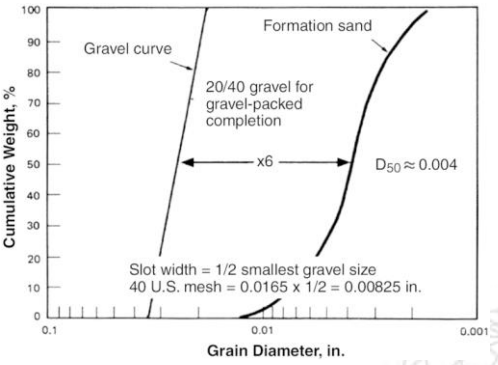
Effect of gravel-sand ratios on sand control



Natural gravel pack

Artificial gravel pack – effective

Artificial gravel pack – sand pumping



Source: http://petrowiki.org/Gravel_pack_design#cite_note-GI-1

Design Criteria – Artificial Gravel Pack

- ✓ Gravel pack should retain most of aquifer material.
- ✓ Screen should retain 90% of the gravel pack.
- ✓ Gravel pack should be clean, well rounded siliceous grains with a Uniformity Coefficient of typically +/- 2.5.
- ✓ Maximum calcareous material = 5% by weight.
- ✓ Gravel pack should be non-contaminated.
- ✓ Gravel pack thickness should be at least 2” and no more than 5” thick.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Design Criteria – Artificial Gravel Pack

Characteristic	Advantages
Clean	Little loss of material during development Less development time
Well-rounded grains	Greater hydraulic conductivity and porosity Reduced drawdown Higher yield More-effective development
90% to 95% quartz grains	No loss of volume caused by dissolution of minerals
Uniformity coefficient of 2.5 or less	Less separation during installation Lower head loss through filter pack

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Design Criteria – Artificial Gravel Pack

- ✓ Use aquifer layer with the finest graded material.
- ✓ Multiply 70% retained size of the aquifer by a factor of 3 to 8. (Factors of >8 may result in sand pumping) and plot on sieve analysis graph.
- ✓ Plot a grading curve through the adjusted 70% retained size, with a Uniformity Coefficient of 2.5

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Artificial Gravel Pack Criteria
US Bureau of Reclamation

Uniformity coefficient (U_c) of aquifer	Gravel pack criteria	Screen slot size
< 2.5	(a) U_c between 1 and 2.5 with the 50% size not greater than six times the 50% size of the aquifer (b) If (a) is not available, U_c between 2.5 and 5 with 50% size not greater than nine times the 50% size of the aquifer	≤ 10% passing size of the gravel pack
2.5–5	(a) U_c between 1 and 2.5 with the 50% size not greater than nine times the 50% size of the formation (b) If (a) is not available, U_c between 2.5 and 5 with 50% size not greater than 12 times the 50% size of the aquifer	≤ 10% passing size of the gravel pack
> 5	(a) Multiply the 30% passing size of the aquifer by 6 and 9 and locate the points on the grain-size distribution graph on the same horizontal line. (b) Through these points draw two parallel lines representing materials with $U_c \leq 2.5$. (c) Select gravel pack material that falls between the two lines.	≤ 10% passing size of the gravel pack

Source: Groundwater Hydrology, 3rd Edition. D.K. Todd & L.W. Mays, 2005.

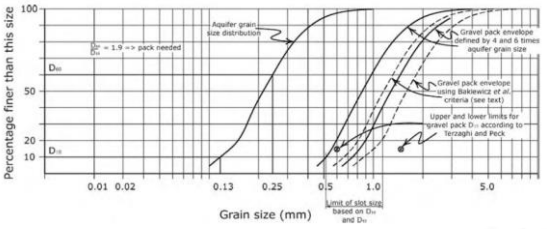
Design Criteria – Artificial Gravel Pack

- ✓ Select appropriate commercial gravel pack, or make one yourself.
- ✓ Select a slot size which will retain 90% of the gravel pack.
- ✓ Estimate volume of gravel pack required for the well. Allow a safety margin, especially if borehole size/stability is uncertain.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Gravel Pack Design – Many Standards…



Source: B. Misstear, David Banks & L. Clark, 2006. Water Wells and Boreholes

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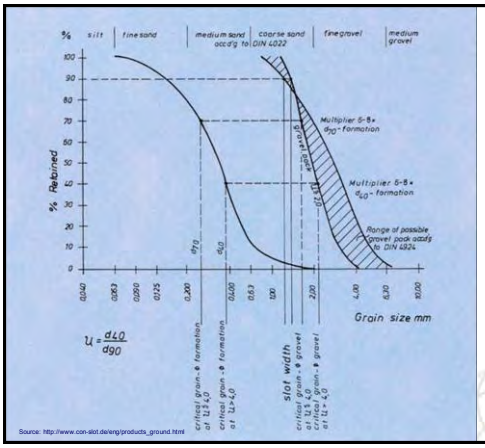


Source: http://www.con-slot.de/eng/products_ground.html

Artificial Gravel Pack Design DIN4924

NORPLAN

Artificial Gravel Pack – Commercially Available Sand Sizes

Gravel Size, U.S. Mesh	Size Range, in.
8/12	.094–.066
12/20	.066–.033
20/40	.033–.017
40/60	.017–.0098
50/70	.012–.0083

Source: http://petrowiki.org/Gravel_pack_design#cite_note-GI-1

NORPLAN

Volume of Gravel Pack Required

ID of Pipe or Bore-hole		Outside Diameter of Well Screen															
in	mm	4 in ft³/ft	102 mm m³/m	6 in ft³/ft	152 mm m³/m	8 in ft³/ft	203 mm m³/m	10 in ft³/ft	254 mm m³/m	12 in ft³/ft	305 mm m³/m	16 in ft³/ft	406 mm m³/m	18 in ft³/ft	457 mm m³/m	20 in ft³/ft	508 mm ms³/m
8	203	0.27	0.03	0.15	0.01	—	—	—	—	—	—	—	—	—	—	—	—
10	254	0.47	0.04	0.36	0.03	0.2	0.02	—	—	—	—	—	—	—	—	—	—
12	305	0.7	0.07	0.6	0.06	0.45	0.04	0.24	0.02	—	—	—	—	—	—	—	—
16	406	1.3	0.12	1.2	0.11	1.05	0.1	0.86	0.08	0.62	0.06	—	—	—	—	—	—
20	508	2.1	0.2	2	0.19	1.9	0.18	1.65	0.15	1.4	0.13	0.8	0.07	0.42	0.04	—	—
24	610	3.05	0.28	2.95	0.27	2.8	0.26	2.6	0.24	2.35	0.22	1.75	0.16	1.4	0.13	1	0.09
30	762	4.85	0.45	4.7	0.44	4.6	0.43	4.4	0.41	4.15	0.39	3.5	0.33	3.15	0.29	2.75	0.26

* Slightly more filter pack is required for telescope-size screens, and slightly less for pipe-size screens.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Practical – Artificial Gravel Pack Design

NORPLAN

Design Criteria – Artificial Gravel Pack

- ✓ Use centralizers & install gravel slowly.
- ✓ Install gravel pack with a sufficient safety margin above the top of the screen.
- ✓ Develop well.
- ✓ Check gravel pack & refill if necessary.
- ✓ Add a 1m sand layer at top of gravel pack to prevent overlying cement grout from invading the gravel.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Formation Stabilizers

- ✓ Keep borehole open and prevent caving from above.
- ✓ Maintain of augment the hydraulic conductivity of the aquifer.
- ✓ Recommended in unstable formations when borehole >2-in larger than the casing.
- ✓ Grain size distribution is large enough so it does not interfere with the natural development of the well.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Design Criteria – Formation Stabilizers

- ✓ Screen size of a naturally developed well should retain 40% of the aquifer, so the formation stabilizer should retain 50% of the aquifer (During development, 50-60% of the stabilizer will be removed).
- ✓ The formation stabilizer should be well rounded, low calcareous material & be uncontaminated.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Formation Stabilizers

	Type of Aquifer		
	Unconsolidated Aquifers	Semiconsolidated Aquifers	Consolidated Aquifers
Composition	Alluvial and glaciofluvial sands, gravels, and beach deposits	Dirty sandstones and siltstones and sandy formations not containing shells	Fractured rock aquifers
Purpose	Provide temporary support for the borehole walls next to the screen	Permanently hold back the formation and provide mechanical retention of small particles	Stabilize the borehole and remove column loads and tension from the completion string
Characteristics of Stabilizer	Grain-size distribution should be equal to or slightly larger than the formation	Grain-size distribution usually is greater than 12 to 13 times the 70% retained size	Gravel-sized materials used with slots >0.08 in (2.2 mm)
Development	Approximately 50% to 60% of the stabilizer is removed during natural development of the formation	None of the stabilizer passes through the screen during development	None of the stabilizer passes through the screen during development
Result	The part of the formation stabilizer that remains next to the screen has hydraulic conductivity similar to the natural formation so that flow is unimpeded; stabilizer also plays a major role in preventing the migration of fine particles into the screen	The formation cannot slump against the screen even if it becomes weakened over time; the porosity and hydraulic conductivity of the stabilizer are high, reducing drawdown in the immediate vicinity of the screen	Enhances probability of laminar flow to the screen and less stress on the borehole and well structure

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

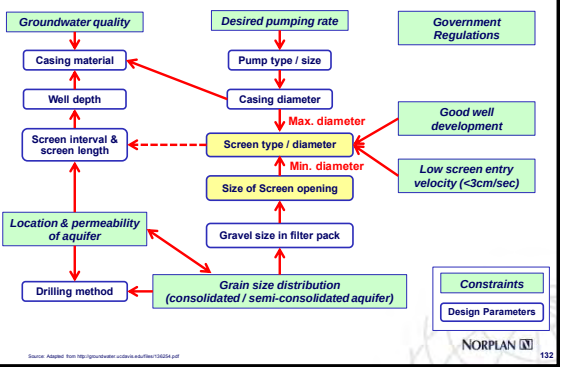
NORPLAN

TOPICS TO BE COVERED

1. Introduction
2. Drilling Methods
3. Casing & Screen Intervals & Well Depth
4. Casing & Screen Materials
5. Pump Type & Size
6. Casing Diameter
7. Gravel Pack Design
8. Screen Type & Slot Size
9. Well Completion
10. Well Development
11. Wellhead Design

NORPLAN

Decision Tree for Water Well Design



Source: Adapted from http://groundwater.ucdavis.edu/files/136254.pdf

NORPLAN

Well Screen Functions

- Allows water to enter the well.
- Keeps selected aquifer material out of the well
- Allows access to the aquifer for well development.

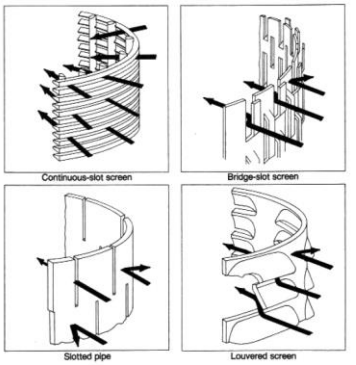
Key Screen Design Features

Feature	Impacts	Objective
Open area	Development Entrance velocity Bacteriological growth	High efficiency and production Low operating cost
Slot geometry	Development	Particle evacuation Low operating cost
Material	Corrosion resistance	Long service life
Strength	Installation	Satisfy load requirements

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 133

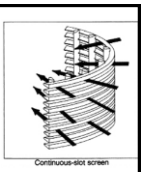
Screen Slot Types



Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 134

Well Screen Materials – Continuous-Slot Wire-Wrap Screen



- ✓ Used for water, oil & gas wells
- ✓ Slot openings number = width in 1/1000in
- ✓ e.g. 10 slot = 0.010in or 0.25mm
- ✓ V-shaped wires prevent screen clogging
- ✓ High % intake areas = lower entrance velocities & lower head losses = lower drawdowns = lower pumping (energy) costs.
- ✓ Good access to gravel pack & aquifer for well development.

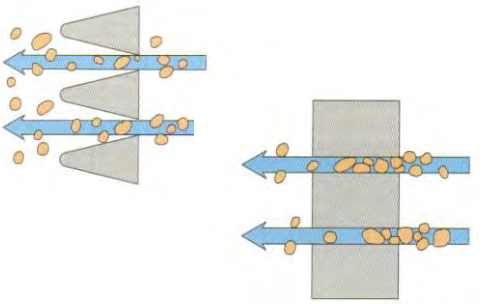
Drawbacks

- ❑ Cost

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 135

Well Screen Materials – Continuous-Slot Wire-Wrap Screen



Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 136

Well Screen Open Areas

Screen Diameter ID		Slot Size	Continuous Slot % Open Area	Louvered (max. open area) % Open Area	Bridge Slot % Open Area	Mill Spotted Vertical % Open Area	Plastic Continuous Slot % Open Area	Slotted Plastic % Open Area
in	cm							
4	10.16	20	25	—	—	—	13	—
		60	52	—	12	5	30	11
8	20.3	30	25	—	—	—	18	8
		60	41	3	6	5	29	14
		95	51	5	—	7	—	—
12	30.48	30	16	—	3	—	—	—
		60	28	4	7	5	—	11
		95	38	7	—	7	—	—
		125	45	9	14	9	—	—
16	40.64	30	16	—	3	—	—	9
		60	28	4	6	5	—	—
		95	38	6	—	7	—	—
		125	45	8	13	9	—	—

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 137

Well Screen Materials – Pre-Pack Screens (e.g. Muni-Pak)

- ✓ Two well screens telescoped inside each other. Annulus pre-filled with filter pack.
- ✓ High % open area.
- ✓ Strong.
- ✓ Ideal where it is difficult to place a gravel pack. e.g. horizontal boreholes.
- ✓ Saves time during installation & logistics.

Drawbacks

- ❑ Cost

Source: http://www.johnsonscreens.com

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 138

Types of Prepacked screens (Petroleum Industry)


Dual-screen prepack


Single-screen prepack


Low-profile prepack

Source: http://petrowiki.org/Slotted_liners_and_wire_wrapped_screens

NORPLAN

Prepacked PVC Screens

Source: http://www.boots.com/PHPpages/products.php

NORPLAN

Well Screen Materials – Pipe-Based Screen

- ✓ Made of perforated pipe covered in continuous-slot screen.
- ✓ Common in oilfield applications, non-vertical wells.
- ✓ Used in deep water wells (e.g. Libya Great Man Made River Project).
- ✓ High strength and durability.

Drawbacks

- ❑ Cost, especially if pipe & screen are stainless steel.

Source: http://www.johnsonscreens.com

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Well Screen Materials – Louvered Screen

- ✓ Made of slots perpendicular to pipe axis, and arranged in rows.
- ✓ Slots are mechanically punched into pipe.
- ✓ Slot size is generally >= 0.04in or 1mm.
- ✓ High tensile & collapse strengths.


Louvered screen

Drawbacks

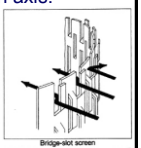
- ❑ Open area usually <8%.
- ❑ Consistent fine-slot configuration is difficult to manufacture. Not suitable for naturally developed wells in fine aquifers.
- ❑ Slots can block during development & not suitable for jetting techniques.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Well Screen Materials – Bridge-Slot Screen

- ✓ Made of slots in rows parallel to the screen axis.
- ✓ Slots are mechanically punched into pipe.
- ✓ Slot size is generally >= 0.04in or 1mm.
- ✓ High tensile & collapse strengths.


Bridge-slot screen

Drawbacks

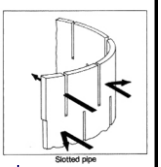
- ❑ Open area usually <5-10%.
- ❑ Slot shape not suitable for naturally developed wells in fine grained aquifers.
- ❑ Slots can block during development & not suitable for jetting techniques.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Well Screen Materials – Mill-Slot Screen

- ✓ Made of slots sawed or cut by torches into pipe.
- ✓ Slot size is generally >= 0.04in or 1mm.
- ✓ High tensile & collapse strengths.


Slotted pipe

Drawbacks

- ❑ Low open area, usually 2 to 4%.
- ❑ Poor corrosion resistance.
- ❑ Difficult to achieve good well development.
- ❑ High maintenance costs.
- ❑ Low well life.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

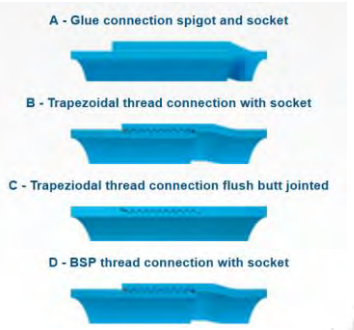
Well Screen Materials – Slotted PVC Screen

- ✓ Made of slots sawed into pipe.
- ✓ Very common for environmental applications.
- ✓ Light weight & easy installation.
- ✓ Corrosion resistant.
- ✓ Cheap.

Drawbacks

- ❑ Low impact strength.
- ❑ Not suitable for deep wells, & hot groundwater.
- ❑ Brittle when cold.
- ❑ Weakens when exposed to sunshine (UV-light)

Well Screen Materials – PVC Joints



Source: http://www.boode.com/PHPpages/products.php

Joining Plastic Casing – BOODE Videos

Source: http://www.boode.com/PHPpages/home.php

Well Screen Materials – PVC Open Area

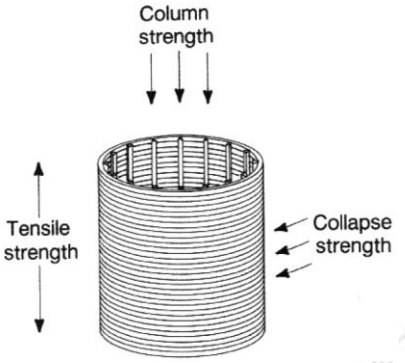
Source: http://www.boode.com/PHPpages/technical-data-slot.php

Well Screen Design – Key Issues

- ➢ The key function of the well screen is to retain native sands & the filter pack, while stabilizing the aquifer.
- ➢ Well screen and gavel pack design requires reliable sediment grain-size analysis.
- ➢ Oversized slots will allow fines to enter the well & may result in sand pumping.
- ➢ Undersized slots will result in higher head losses & may prevent effective well development.
- ➢ Slot sizes generally range from 0.2 mm to 5 mm.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Design Criteria – Screen Strength



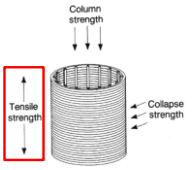
Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

Design Criteria – Screen Strength

- Strength requirements determines material & type of screen.
- Column loading: when screen assembly is not hanging freely in the borehole during installation.
- Tensile loads: when long sections of screen & casing are installed.
- Collapse forces: when borehole material collapses around the screen, gravel packs settle (bridging), or differential hydraulic pressures occur during pumping.
- Greatest risk is during well installation & development.

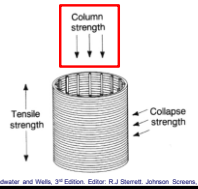
Design Criteria – Screen Tensile Strength

- ✓ Include the weight of all the screen and pipe.
- ✓ $Safe\ Hanging\ Weight = \frac{Screen\ Tensile\ Strength}{2}$
- ✓ Tensile strength of perforated pipe = ½ blank pipe.



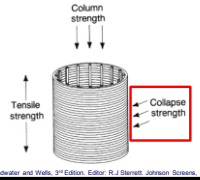
Design Criteria – Screen Column Strength

- ✓ Determined by non-slotted portion of pipe.
- ✓ Determined by vertical rods in continuous slot screen.
- ✓ Column strength is reduced if the screen assembly is not kept vertical – use centralizers!
- ✓ Column strength is important *before* gravel packing & development.



Design Criteria – Screen Collapse Strength

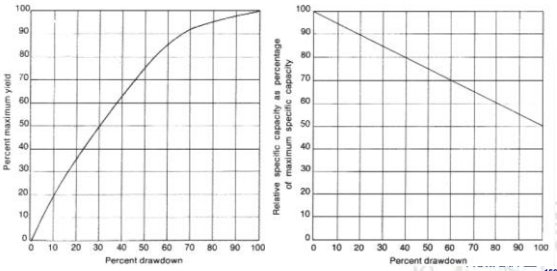
- ✓ Safe Depth estimated from drillers experience:
  - 0.5 psi/m (0.03 bar/m)
  - 0.20 psi/m (0.05 bar/m)
  - 1 psi/m (0.07 bar/m)
- ✓ Hydrostatic pressure of fresh water = 0.1 bar/m
- ✓ Many wells have worked successfully for many years with < full hydrostatic gradient.



Practical – Screen Strength

Design Criteria – Screen Unconfined Aquifer

- ✓ Unconfined Aquifers: screen lower 1/3 to ½.
- ✓ Non-homogenous unconfined aquifers: screen permeable layers in the lower portion of the aquifer.



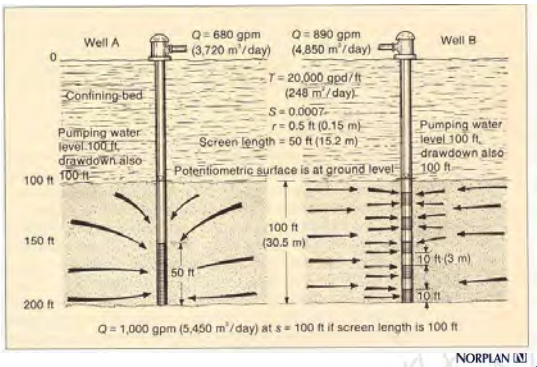
Design Criteria – Screen Confined Aquifer

- ✓ Confined aquifers - homogenous: screen 80-90% of thickness.
- ✓ Confined aquifers – non-homogenous: screen 80-90% of most-permeable thickness.
- ✓ Centre screened section in the aquifer.
- ✓ Aquifer will behave as unconfined if drawdown is lower than top of aquifer.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Design Criteria – Screen Length



Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Design Criteria – Screen Diameter

- ✓ Determined by required pump size.
- ✓ Doubling screen diameter increases well efficiency by +/- 10% only in unconfined aquifers!

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Design Criteria – Slot Size

- ✓ The screen should retain 90% of the artificial gravel pack.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

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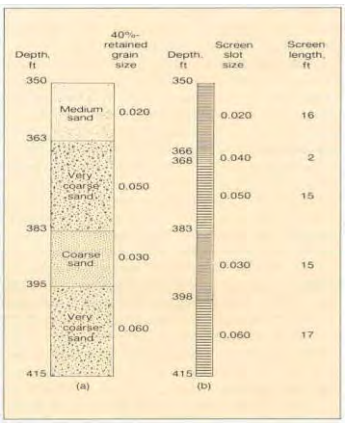

Screen Slot Sizes

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Design Criteria – Average Entrance Velocity

$$Entrance\ Velocity = \frac{Well\ Yield}{Total\ Screen\ Open\ Area}$$

Screen entrance velocity < 0.1 ft/sec (0.03m/sec)

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Design Criteria – Average Entrance Velocity

Table 5.4.2 Optimum Entrance Velocity of Water Through a Well Screen (after Walton[101])

Hydraulic conductivity of aquifer (m/day)	Optimum screen entrance velocity (m/min)
> 250	3.7
250	3.4
200	3.0
160	2.7
120	2.4
100	2.1
80	1.8
60	1.5
40	1.2
20	0.9
< 20	0.6

Source: Groundwater Hydrology, 3rd Edition; D.K. Todd & L.W. Mays, 2005

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Design Criteria – Up-hole Velocity

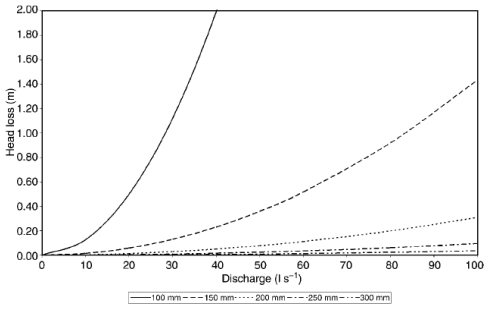
$$Uphole\ Velocity = \frac{Well\ Yield}{Minimum\ Screen\ Cross - Sectional\ Area}$$

Up-hole velocity < 5 ft/sec (1.5 m/sec)

Source: Groundwater and Wells, 3rd Edition, Editor: R.J Sterrett, Johnson Screens, 2007.

NORPLAN 164

Up-flow Head Losses in Screen



Screen Length = 10 m

Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

NORPLAN 165

Sources of Well Losses

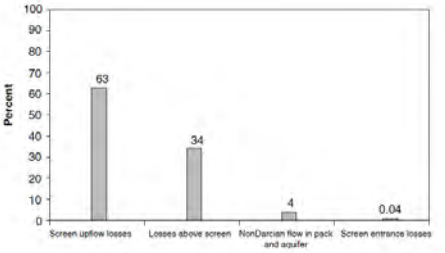
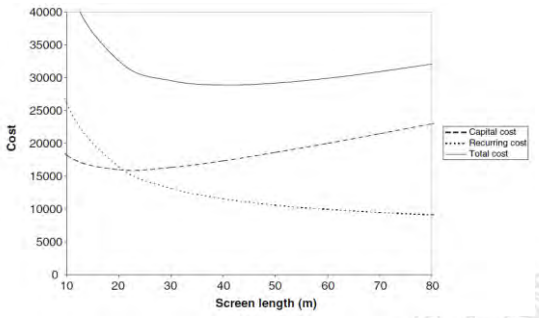


Figure 4.10 Average theoretical contributions to the well loss coefficient C, for 17 test wells in Bangladesh (based on data in Table 2 in Barker and Herbert, 1992b)

Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

NORPLAN 166

Screen Length – Economic Considerations



Source: B. Misstear, David Banks & L. Clark, 2006; Water Wells and Boreholes

NORPLAN 167

Practical – Screen Entrance Velocity

NORPLAN 168

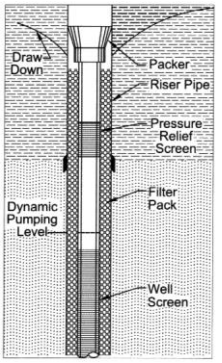
Design Criteria – Pump Placement

- ✓ Pump intake placement should be below the maximum anticipated pumping water level.
- ✓ Ideally it should not be in a screened section due to possible high screen entrance velocities…. But some studies show this may not be a problem.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

Design Criteria – Pressure Relief Screens



- ✓ Short screen installed in casing to reduce pressure differential between pumping water level inside the well and the water level in the gravel pack.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN

TOPICS TO BE COVERED

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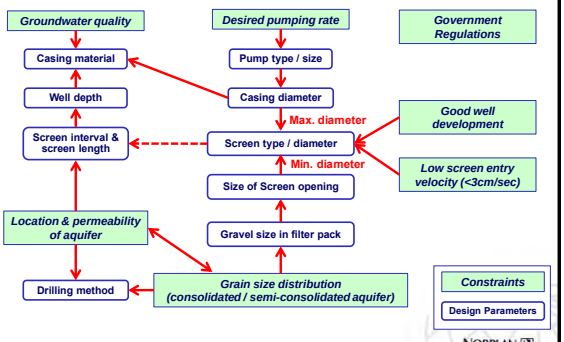
8. Screen Type & Slot Size
9. Well Completion
10. Well Development
11. Wellhead Design

NORPLAN

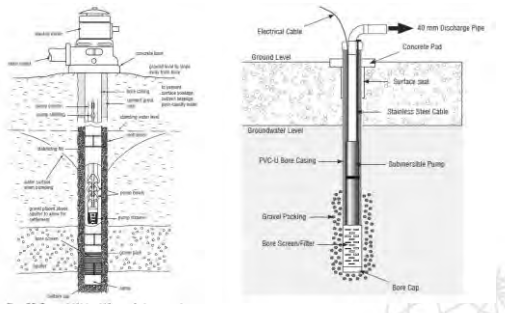
Decision Tree for Water Well Design



Source: Adapted from http://groundwater.ucdavis.edu/files/136254.pdf

NORPLAN

Typical Well Design



Source: Minimum Construction Requirements for Water Bores in Australia, 3rd Edition, Feb 2012.

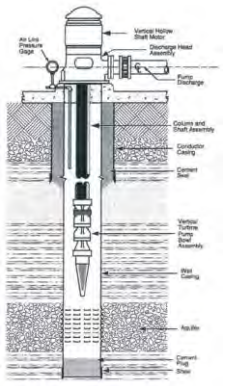
NORPLAN

Cementing

- ➢ Neat cement grout used to seal annulus between ground surface and the aquifer, and the space between overlapping casing.
- ➢ Used in well abandonment.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN



Potable Well Design California, USA

Borehole diameter: 26"
Casing diameter: 16"
Casing material: stainless steel
Well depth: 1,000'
Screen: 400', stainless steel, louvered
Filter pack: silica sand
Well completion: cement grout
Well development and test pumping.

Cost: $750,000 to $800,000,
Budget Cost: $1,000,000 including surface storage, treatment etc.

Source:http://www.and.org/engineering/water-supply-well-los-angeles.php

NORPLAN

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PVC Casing & Screen Selection & Precautions

Source: http://www.boode.com/PHPpages/technical-data-pvc-well.php

BOODE waterwell systems

PVC Well Casing and Screen - Selection and Precautions

Source: http://www.boode.com

NORPLAN

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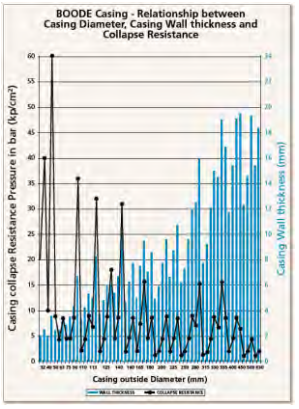

Source: http://www.boode.com

Collapse Resistance PVC Casing

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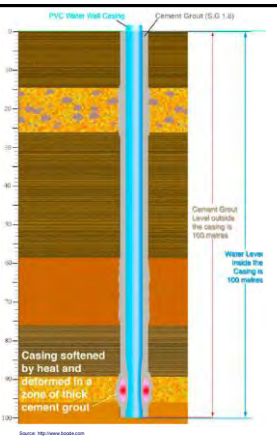

Source: http://www.boode.com

Casing deformed by heat and Hydraulic pressure in a wide zone of Cement Grout outside the casing

NORPLAN

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Casing Materials - Polyvinyl Chloride (PVC)

PVC strength reduces rapidly with increasing temperature.

Heat of hydration from cement curing may cause failure.

Source: S. J. Schneider, 2012, Water Supply Well Guidelines for Use in Developing Countries, Second Edition.

NORPLAN

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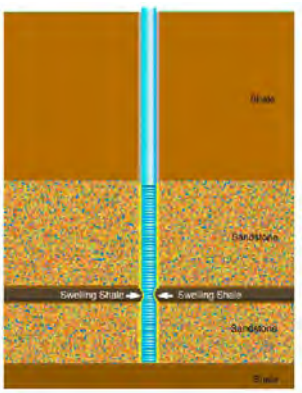

Source: http://www.boode.com

Screen deformed by Formation Pressure – Swelling Shale

NORPLAN

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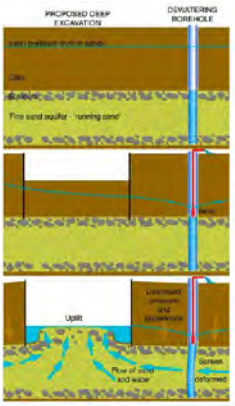
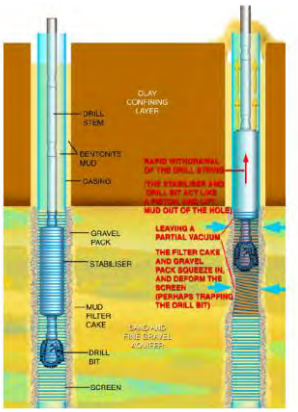
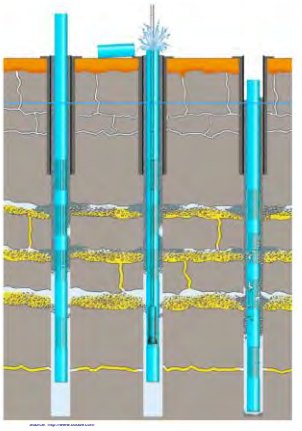


Casing deformed by Formation Pressure exerted by Geotechnical Failure



Screen Deformation Created by Partial Internal Vacuum

Deformation of the Borehole Screen by Compression



Screen Fracture from External Impact

Be careful when Installing PVC!!!

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10. Well Development
11. Wellhead Design

Well Development

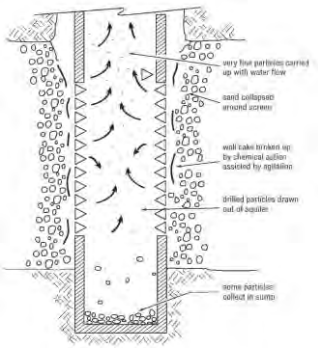
The objectives of water well development are:

1. Improve the hydraulic efficiency of the well by removing fines from the formation near the well.
2. Reduce sand pumping to <25mg/L.
   Sand pumping can reduce the life of the pump, and cause sand blasting in the well casing.

Source: Groundwater and Wells, 3rd Edition. Editor: R.J Sterrett. Johnson Screens, 2007.

NORPLAN 187

Well Development



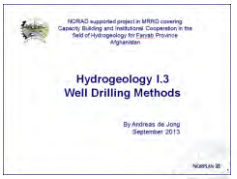
Source: Minimum construction requirements for water bores in Australia 3rd Edition, 2012.

NORPLAN 188

Well Development Methods

Well development methods utilize mechanical, hydraulic or chemical techniques in order to maximize well production and efficiency. Technologies include:

a) Airlift pumping
b) Surging
c) Swabbing
d) Brushing
e) Jetting
f) Chemical treatment
g) Hydraulic fracturing



NORPLAN 189

TOPICS TO BE COVERED

1. Introduction
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11. Wellhead Design

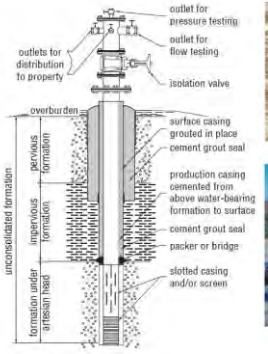
NORPLAN 190

Flowing artesian bore (prior to site cleanup)

Source: Minimum Construction Requirements for Water Bores in Australia, 3rd Edition, Feb 2012.

NORPLAN 191

Flowing Artesian Wellhead Design



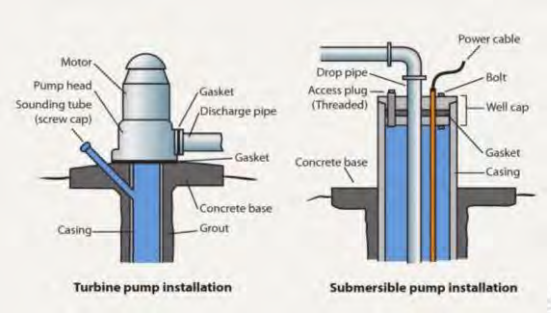
Water supply under control

Water supply out of control

Source: Minimum Construction Requirements for Water Bores in Australia, 3rd Edition, Feb 2012.

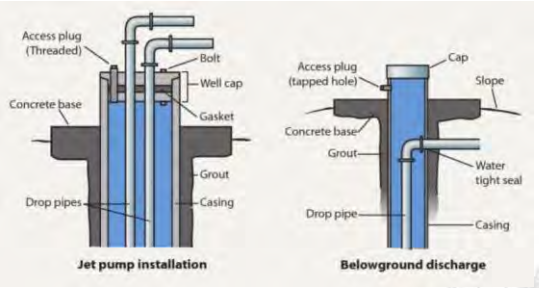
NORPLAN 192

Minimum Well Design Standards – California



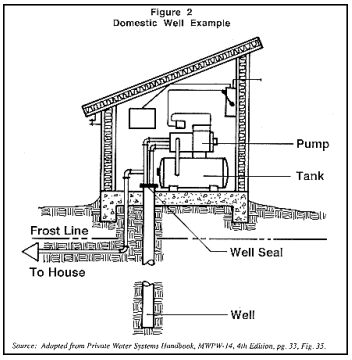
Source: T. Harter & L. Robins, 2009, Watersheds, Groundwater and Drinking Water: A Practical Guide, UCANR Publications, 274 pp.

Minimum Well Design Standards – California



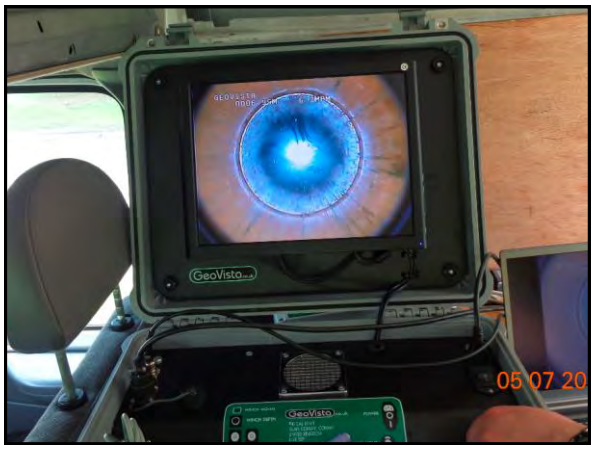
Source: T. Harter & L. Robins, 2009, Watersheds, Groundwater and Drinking Water: A Practical Guide, UCANR Publications, 274 pp.

Well House – Private Well



Source: http://www.amatural.org/environmental_management/septicfact.htm

Practical – Wellhead Design



Thank you
for your attention!