University of Southern Queensland
Faculty of Engineering and Surveying

Sealing Works Performance Study

A dissertation submitted by

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In fulfilment of the requirements of

Course ENG4111 and 4112 Research Project

Towards the degree of

Batchelor of Engineering (civil)

Submitted: October, 2009

Abstract

Bitumen sprayed seals are an effective and economical road surfacing technique utilised widely across the world. The premature failure of road surfacing can be detrimental to road user safety with some surfacing failures causing a reduction in skid resistance, large profile irregularity and loose stone on the road surface.

This research project was commissioned by the Department of Transport and Main Roads, Queensland. The objective of this dissertation is to develop and implement an evaluation system to ensure effective investigation, design, application and evaluation of bitumen seals. The objectives are focused on roads in the Far North region of Queensland, Australia.

Premature flushing of sprayed seals has been identified as the failure mode of greatest consequence. Flushing causes a reduction in skid resistance and the increased propensity for road crashes. The New Zealand TNZ P17 Performance specification predicts the premature flushing based on texture depth measurements one (1) year after the seal is constructed. The specification has been successfully implemented in New Zealand and America.

The TNZ P17 specification has been adapted to the Far North region road network. However, due to inaccurate data used to modify the specification models the predictions may not reflect the actual seal behaviour in the Far North region. Further data collection and refinement is required.

This dissertation details the process for adapting the TNZ P17 performance specification to any region in the world, provided that accurate seal data exists.

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Acknowledgments

The author would like to thank: Associate Professor Ron Ayers for his help and guidance; Don Wallace and Christine Stevenson of the Department of Transport and Main Roads, Far North Region, their valuable time and assistance; and my wife, Joanne for her support and understanding during the preparation of this project.

Andrew Armstrong

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Glossary

AADT	Annual Average Daily Traffic, typical number of vehicles using a section of road in one day
AAPA	Australian Asphalt Pavement Association, AAPA represents Australia's manufacturers and practitioners of asphalt and other bitumen products
ALD	Average Least Dimension of an aggregate particle
ARMIS	A Road Management Information System
ARRB	Australian Road Research Board
Austroads	Austroads is the association of Australian and New Zealand road transport and traffic authorities and aims to promote improved road transport outcomes
C170	grade of bitumen, where the viscosity at 60^{o}C is 170 Pa.s
Chainage	measurement along the length of a road from a reference point
DTMR	Department of Transport and Main Roads, Queensland state road authority, formally know as the department of Main Roads
elv	equivalent light vehicles, assumes a heavy vehicle is the equivalent of 10 light vehicle
LGA	Local Government Agency

MATLAB	A high-level language program that enables you to perform computationally intensive tasks
MPD	Mean Profile Depth, unit of texture depth measurement by a mobile sensor
OH&S	Occupational Health and Safety
SPTD	Sand Patch Texture Depth
SRA	State Road Authority
TNZ	Transit New Zealand, road authority of New Zealand
vpd	vehicles per day

1 Introduction

Bitumen sprayed seals are an effective and economical road surfacing technique utilised widely across the world. Countries such as Australia, New Zealand and South Africa are considered the world leaders in the delivery of high quality bitumen sprayed seals. This expertise is necessitated by the widely separated population centres and limited funding available.

In Australia, the mean seal life on State controlled roads is 10.3 years. In some situations the design life of seals are not being met, with anecdotal evidence suggesting that the number of seals failing prematurely is increasing. The premature failure of road surfacing can be detrimental to road user safety with some surfacing failures causing a reduction in skid resistance, large profile irregularity and loose stone on the road surface. The re-treatment of failed seals is costly, in some circumstances costing more than the initial seal treatment.

The Queensland Department of Main Roads, Far North region, has commissioned this project to develop and implement an evaluation system to ensure effective investigation, design, application and evaluation of bitumen seals.

In this region some seals can display fattiness or stripped surfaces due to a number of contributing parameters. Little research has been done investigating the contributions of these parameters. To date there is not an evaluation system in place to investigate seal performance with respect to the parameters considered at the theoretical seal design stage. Main Roads (Far North region) believes that information gained from such an evaluation system will provide valuable information that will lead to better seal performance.

The premature failure of bitumen sprayed seals is a world-wide problem. While this research project will only consider the small study area of the Far North Queensland region, this research is intended to have relevance across the globe.

1.1 Background

The department of Main Roads, Queensland, is the State Road authority managing 33,500km of state-controlled road network as part of an integrated transport system. State controlled roads account for approximately 20% of the state's total road network and carry approximately 80% of the state's traffic. The state is divided into 12 regions, with each responsible for the state-controlled road network in the region.

Mid 2009 saw the amalgamation of the Department of Main Roads and Queensland Transport. The new organisation is now the Department of Transport and Main Roads, however for this project will be referred to as the Department of Main Roads.

The Far North region is the study area researched for this project and is shaded in figure 1-1. The region is 419,047 sq km, extending from Cardwell on the east coast, west to Croydon and north to include the islands of the Torres Strait. The region supports a population of approximately 250,000 people.

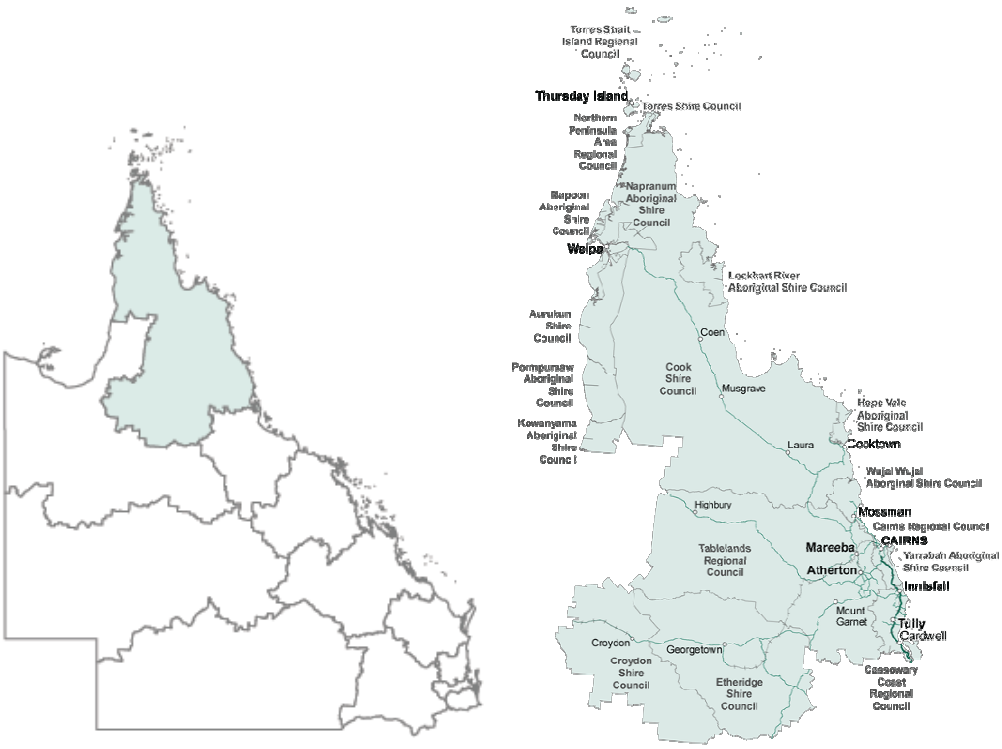

Figure 1-1Far North Region Map

1.2 Aims & Objectives

The project aims to develop and implement an evaluation system to ensure effective investigation, design, application and evaluation of bitumen seals for the Far North region of the Department of Main Roads.

1.3 Specific Objectives

The specific objectives for this project have been taken from the project specification. This section will explain each of the objectives.

1. *Research existing seal evaluation systems, seal defects and associated mechanisms, seal performance criteria testing methods and seal design rationale.*

The first point of this project is to research information to better understand what is required and how a solution may be met. To understand how a seal will fail, it is important to research the seal defects, associated mechanisms and how they affect the performance of the seal. To avoid re-inventing an evaluation system, any existing systems are researched to assess the relevance to the failure modes.

2. *Decide which seal properties to evaluate eg. Skid Resistance, Texture depth etc.*

Based on the research, the seal properties to be evaluated are chosen based on a number of factors pertaining to the failure mode and its implication.

3. *Develop and document a system that will evaluate as-constructed sealed works properties against the properties predicted by design.*

Having selected a seal property, or properties, a system is developed to assess how the seal property performs. The system may already exist, for which it will need to be assessed for suitability in the study area.

4. *Select a suitable geographical area in which to implement a trial of the evaluation procedure.*

The study area is selected as to reduce the number of variables that may affect the evaluation system.

5. *Carry out the trial study, identifying sealed works suitable for model. eg. re-seal works, analysing the sealed works (design and as-constructed) and correlating between design and as-built seal properties.*

Data is collected within the study area to assess the evaluation system with respect to the data. The Department of Main Roads holds a large collection of current and historical road asset data.

6. *After analysing the results of the trial study, carry out any necessary modifications to the proposed evaluation system.*

Depending on the suitability of the evaluation system, modification of the models used in the system may require modification to better reflect the seal property behaviour in the study area.

7. *Report on the results of the project in the required oral and written formats.*

The process used to develop the seal performance evaluation system will be documented. This will ensure that the model developed specifically for the study area may modified for use outside the study area.

If time permits:

8. *Develop a testing plan to be used on future sealed works.*

A testing program would be used to ensure that seal data relevant to the seal evaluation system is collected to further develop and refine the system. The program should detail the seal properties to be assessed, testing location and a testing schedule to ensure that the data is collected at the correct seal life.

9. *Assess other sealed works for further modelling.*

Apply the testing schedule to sealed works identified for input into the evaluation system.

1.4 Dissertation Overview

Chapter 1 covers the introduction, background and a brief summary on the specific objectives of this project.

Chapter 2 encompasses the literature review with an introduction and summary of elements of sprayed seal performance. The review covers terminology and definitions, existing performance evaluation systems and seal design.

Chapter 3 describes the methodology and procedures employed to deliver this project.

Chapter 4 analyses and discusses the results of the projects. The discussion covers the evaluation system models, the model development and data collection.

Chapter 5 surmises the conclusions that resulted from the project, as well as commenting on the benefits of the project and possible future works.

2 Literature Review

2.1 Introduction

The literature review is a major component of the research project. The review is used to collate information relevant to the project objectives. The focus of this literature review is on sprayed sealing and associated design, performance and defects. An investigation into the existing seal evaluation systems and performance models was also performed.

2.2 Sprayed sealing

Sprayed seal works is an important component in the performance of road pavements in Australia. According to Austroads (2009), currently there is no surfacing other than a sprayed seal that can be considered as an alternative, given the distance involved and the limited funding available. A widely separated population necessitates development of outstanding skills in low-cost roadmaking techniques of which the use of sprayed sealing treatments is a key element. Thus such countries as Australia, New Zealand and South Africa are more highly developed than most other countries at effectively using sprayed seals as initial treatments and re-treatments.

Australian Asphalt Pavement Association, AAPA, (2009) indicates that sealing practices and materials have improved over the years to a stage that sprayed sealing can be carried out successfully on pavements carrying from as low as 100vpd to as high as 20 000vpd. It is important to the national economy that sealing and maintenance of the sprayed seal road network is kept to a sufficiently high standard.

Austroads (2003a) states that successful sprayed seal work involves:

- Selection of treatments appropriate to site conditions and performance requirements.
- A design process for determination of binder and aggregate application rates.
- Selection of appropriate equipment and suitably trained personnel.
- Control of aggregate and binder supply.
- Stockpile site management and preparation of aggregates.
- Selection of and incorporation of appropriate cutter oil proportions and/or binder additives depending on climate, weather and traffic conditions.
- Spraying of binder at correct temperature and application rate.
- Prompt spreading of aggregate at correct spread rate.
- Effective rolling and aftercare.
- Traffic site management and other OH&S issues.

Sprayed seal work requires judgment and skill in making decisions that are site specific due to traffic and surface conditions, effects of the condition of aggregate materials and the effect of weather conditions at the time of work.

2.2.1 Types of sprayed seals

The correct choice of sprayed seal treatment is imperative to the success of the treatment. AAPA (2009) details various treatments and their application. Such treatments are:

- Priming
- Primersealing
- Surface enrichment
- Seal coats
- Retreatment

2.2.2 Priming

The application of a suitable primer to a new or reconstructed, prepared pavement as a preliminary treatment. This is to hold the pavement and to assist in achieving a good interfacial bond between the pavement and the seal coat or asphalt.

The function of the primer is to deal with surface dust, seal surface pores in the pavement material, strengthen the pavement near its surface and to waterproof the pavement binding material.

It is recommended to prime all freshly constructed pavements prepared for initial treatments in warmer and drier times of the year. Where traffic exceeds 300 vehicles per lane per day (v/l/d), the alternative of primersealing is recommended to avoid inconvenience to traffic.

2.2.3 Primersealing

Primersealing is the application of a suitable primerbinder, covered with aggregate. This is applied to a new or reconstructed prepared pavement as a temporary treatment or to hold the pavement. This provides a wearing surface until a final seal coat or asphalt can be applied. Penetration of the binder into the pavement is generally not more than 5mm.

Primerseals require a final seal treatment when the bitumen is nearly or fully oxidised. Regular inspection of the primerseal should be carried out to determine when retreatment is required.

2.2.4 Surface enrichment

Surface enrichment is the application of a bituminous material to an existing bituminous surface with the aim to increase the binder content of the surface and extend its life. This is generally done without aggregate but may be done using a light cover of small aggregate to minimise delay to traffic. This treatment is usually most suited to low traffic areas or where traffic may be detoured.

2.2.5 Seal coats

Seal coats are an application of bituminous material covered with a layer of aggregate. These are generally subdivided into 2 groups, initial treatments and re-treatments.

An initial treatment is a seal on a newly constructed or reconstructed road pavement. This may include more than one seal provided it was included in the original treatment design.

The most common forms of initial treatment are:

- A prime and seal
- A primerseal followed by a final seal
- A light seal (prime and seal) followed by a final seal.

The most common seal coat is the single application (single/single) seal, which is one application of binder with an application of one size of aggregate.

A Multiple application (double/double) seal is more than one application of binder with each application covered with aggregate. Generally these seals do not exceed two applications with the second coat of aggregate being half the size of the initial aggregate. Predominantly double/double seals are used to provide a heavy sprayed seal coat in areas of high loading and stress, where a more robust treatment is required than that provided by a single/single seal.

Two aggregate seals (single/double) consist of one coat of binder and two applications of aggregate. The aggregate is usually of two sizes with the second application being half the size of the first. This is usually only used in the case of bleeding seal coats, to provide sufficient surface texture and a running surface to allow the bitumen to set.

2.2.5 Retreatment

This is more commonly referred to as a reseal, and is a periodic maintenance seal over an existing bituminous surface. The need to reseal is influenced by:

- Standards set by the authorities
- Availability of funds
- Criteria assessed
- Maintenance practices

2.3 Materials

Sprayed seals consist mainly of only two (2) resources, a bituminous binder and aggregate.

2.3.1 Bitumen

The bituminous binder used predominantly in sprayed seal surfacing is produced from the refining of crude petroleum oil. Bitumen behaves as a thermoplastic material, meaning that it will soften with the application of heat and returns to its initial state on cooling. AAPA (2009) recognises the properties that make bitumen a desirable binder material for road manufacture are:

- Chemical inertness
- Water resistance
- Natural adhesiveness
- Flexibility and ductility
- Durability
- Non-toxicity

In other countries, such as America, bitumen is referred to as 'asphalt' or 'asphalt cement'. The American term leaded to confusion as in most countries, including Australia, asphalt describes a mixture of bitumen and aggregate which forms a paving material.

The crude oil is distilled by heating, to evaporate the lighter fractions and leave a liquid residue. This residue is processed to produce a soft bitumen. Bitumen hardens by reacting with oxygen in the air. The higher the surface temperature, the faster the oxidation rate.

Paving grade bitumen is covered by Australian Standard AS2008 "residual bitumen for pavement" and appropriate test methods are specified in Australian standard AS2341.

2.3.2 Aggregate

Aggregates are classified based on physical properties. Aggregate classification provides for efficient usage of available materials and enables an aggregate of adequate quality to be specified for a particular application. Sprayed seals are commonly characterised by the nominal aggregate size, however it is the Average Least Dimension (ALD) of the aggregate that is an important characteristic for the seal design. The ALD is the smallest dimension of an aggregate particle and is generally vertical when the aggregate is in its most stable orientation. Figure 2-1 displays an aggregate particle with dimension A being the average least dimension.

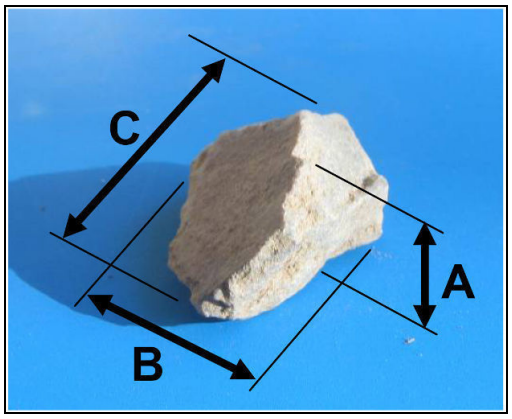

Figure 2-1 Aggregate particle

Aggregates should be specified in accordance with the traffic loads and expected seal life. AAPA (2009) suggests that where appropriate a lower satisfactory classification could be used on a road with low traffic volume or short design life. The Australian standard AS 2758 reflects the quality of local material as well as a basic minimum standard and performance criteria. The aim of the specification is to obtain aggregates that are:

- Sound and durable
- Well shaped (cubical)
- Clean and uniformly graded
- Resistant to polishing

The function of aggregate in sprayed seals is to resist abrasion and to transmit the wheel loads to the base.

Aggregate grading is usually specified by the following requirements

Specified size – 60-70% should be in range

Tolerance on oversize – 15-20% maximum

Tolerance to undersize – 2% maximum dust content

2.4 Seal Design

Research by Holtrop (2007) found that Australian practice compares favourably against the practices used in New Zealand and South Africa, and the difference is mainly only in the detail.

In 1992, Austroads commissioned a project with the aim of improving reliability of design by measuring existing pavement conditions and their influence on the design process and sprayed seal performance. The provisional 'Revision 2000' design method was the outcome of the project (Austroads 2003).

The Austroads 'The design of Sprayed Seal Surfacing (2006)' is the design method used currently in Australia. This update is derived from a combination and consolidation of the two earlier guides; 'Practitioners guide to the design of sprayed seals' (Austroads 2002) and 'Austroads Provisional sprayed seal design method' (Austroads 2001). The document has been extended to include a section on treatment selection. Correct treatment selection is essential, as failure to do so may result in a treatment that cannot provide the appropriate surfacing characteristics and performance.

Several aspects of the seal design method still need to be investigated and require collection of further data. These aspects include matters such as:

- Potential embedment of aggregate.
- The effect of large heavy vehicles on the rolling/packing of aggregates in sprayed seals.

2.4.1 Design Philosophy

The design philosophy of the current Austroads sprayed seal design guide is based loosely on the concept originally proposed through Austroads 2009, by Hanson (1935) (Austroads 2003b), '*To achieve a satisfactory sprayed seal, the voids within the sealing aggregate mosaic should be filled to about one-half to two-thirds with binder'*. The design philosophy adopted applies principally to the design of the most common type of sprayed seal, the single/single seal using conventional bitumen. Satisfactory performance has been given by other seal types that have been designed using the philosophy based on the single/single seal. Some assumptions used in the design of the single/single seal are:

- Aggregate is single sized and of appropriate quality
- Average least dimension (ALD) of the aggregate must be representative of the aggregate being used
- Design traffic volume is expressed in vehicle/lane/day and based on Average Annual Daily Traffic (AADT)
- Aggregate is spread in a uniform layer of one stone thickness with the least dimension near vertical
- There is no separate allowance made for whip-off of the aggregate
- Aggregate spread rate determines the inter-aggregate void space in the seal layer, and hence the amount of binder required.
- A single layer of aggregate particles settle with typically 40-60% voids after orientation and packing.
- Binder rise should be a minimum of about 35-40% up the height of the aggregate particles after initial rolling and increase to 50-65% about two (2) years after construction
- Aggregate particles may embed into the base
- Reseals interlock with the existing surface
- Binder may be absorbed into the base
- The proportion of voids to be filled with binder may be varied to optimise requirements.
- Preliminary treatments have been correctly designed and applied

- All application rates determined by this method are expressed in L/m^2 of residual binder at the standard reference temperature of 15^oC.

The general schematic of the process for determining the binder application for a single/single seal is below.

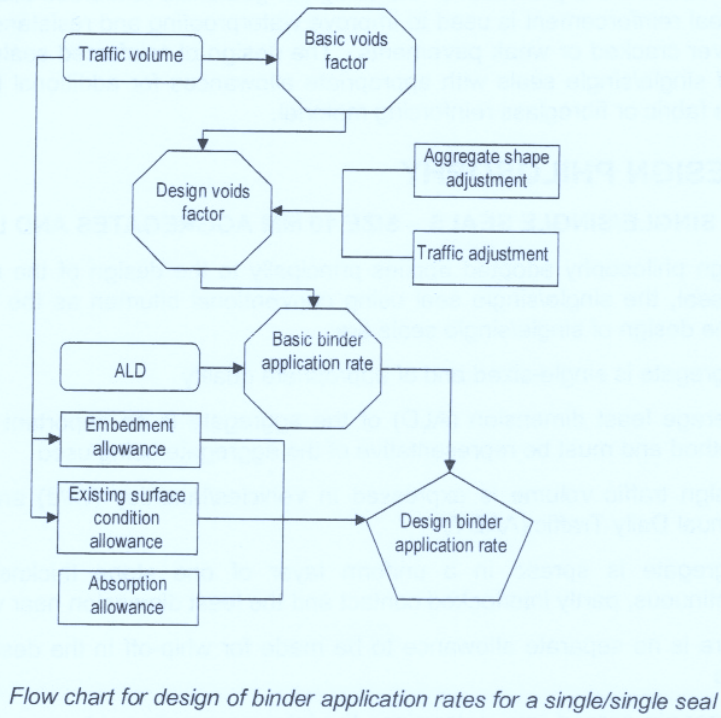

Figure 2-2 Seal design process schematic
Source: Austroads 2009, Section 5, Page 13

Holtrop (2007) has raised some issues with the design method, that are:

- Concerns about the quality of some naturally accruing granular base materials not being able to carry large vehicles without deformation, or seals flushing early in life. The seal design alone can not be expected to compensate for this.
- Concerns with the standard of preparation of new pavements. In particular where insufficient time is allowed for the pavement surface to dry back adequately.

- Concerns with the standard of preparation and timing of maintenance of existing pavement prior to resealing. Complaints are received about seals flushing, but inspections reveal the flushing mainly occurs over fresh maintenance patches.

2.5 Performance

2.5.1 Seal life

In most countries a sprayed seal is regarded as a maintenance treatment with a service life of less than five years. In Australia and New Zealand sprayed seals have had considerable development, resulting in a seal life of approximately 10 years or more under reasonable heavy traffic.

Oliver (1999) developed a national questionnaire on seal performance including a question on seal life. The mean lives report by Australian road authorities are given below.

Table 2-1 Mean life of seals for specific aggregate sizes

Nominal Seal Size (mm)	Mean Seal Life (years)
7	6.5
10	10.0
14	11.7
>16	13.2

These values coincide with the ARRB Transport Research Report ARR326, indicating seal life expectancies based on a survey of road authorities in Australia and New Zealand.

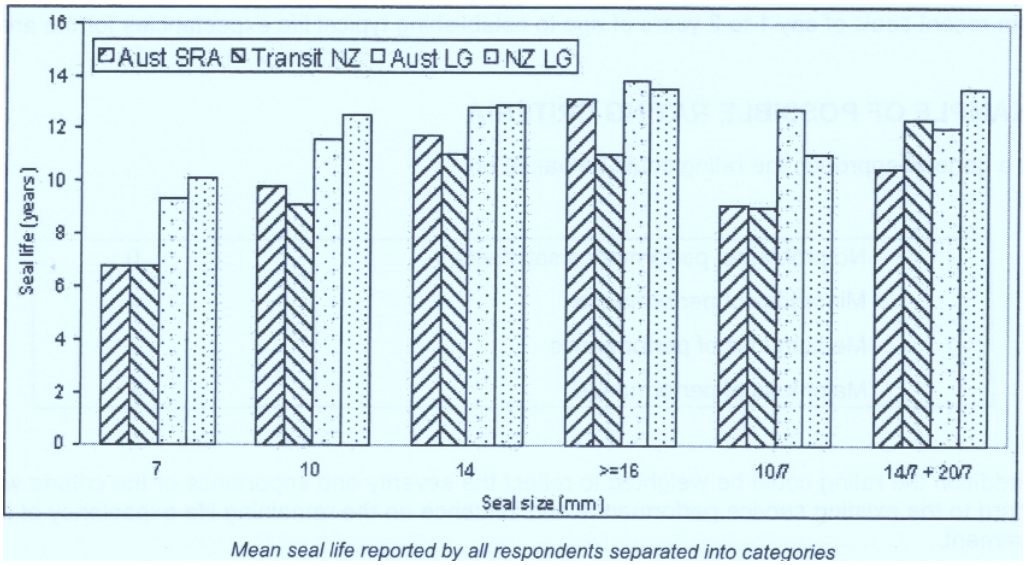

Figure 2-3 Survey of mean seal life in Australia and New Zealand
Source: ARRB Transport Research Report ARR326

The seal lives reported by the local governments are greater than that of the State road authorities. Such a difference in life expectancy may be due to a variety of factors including reduced traffic loads or a greater tolerance of defects on the local government's roads.

2.6 Performance criteria

Grobler et al. (2003) surmises that, pavements constructed with natural gravel layers may have an almost infinite life. That is, provided that moisture is kept out, the subgrade is strong and the gravels used on the pavement layers are densely compacted and have high enough bearing strength to carry the loads applied. Therefore surfacing is an integral factor to the longevity of a pavement.

AAPA (2009) stated, a sprayed seal correctly designed and constructed on a sound pavement, is mainly influenced by the following factors with regards to life expectancy.

- Size and quality of aggregate
- Durability of bituminous binder
- Design of binder application rates
- Climatic conditions
- Traffic volume and composition

In terms of performance criteria it is usual to describe performance measured against failure criteria.

Seal performance criteria have been defined as 'avoidance of certain failure parameters' (Robertson et al, c.1990) Milne et al. 2005, p3) and according to Milne et al. (2005), these failures being:

- Permanent deformation (punching, rotation of seal stone reducing voids)
- Early rutting of the supporting base
- Fatigue cracking
- Low temperature cracking
- Moisture damage
- Adhesion failure

Empirical research by Milne et al. (2005) has demonstrated that the life of a seal is dependant on the following performance of the base regarding:

- Permanent base deformation: punching (associated with flushing) and rutting
- Moisture damage

And dependant on the seal material behavioural components for:

- Permanent deformation or loss of texture: rotation of seal stone, reducing voids, failure of 'mat' behaviour allowing punching
- Fatigue cracking
- Low temperature cracking
- Adhesion failure (stripping)
- Aggregate crushing or polishing

Therefore failure parameters applicable to the road surfacing seal will be:

- Deformation and texture loss: rotation and punching of the seal stone
- Cracking: fatigue (ageing of binder and loss of elasticity)
- Low temperature brittleness
- Loss of adhesion (of stone to bitumen, and bitumen to base)
- Aggregate (crushing or polishing)

The majority of these parameters are influenced heavily by the condition of the bitumen and is emphasized by Oliver (1990, p1) '*The life of sprayed seals is critically dependant on the hardening rate of the binder'*.

In addition to the above, Austroads (2003b) has established the following parameters that require assessment for the monitoring of the performance of road surfacings.

- Pavement surface shape
- Skid resistance
- Surface texture
- Noise
- Rutting and shape loss
- Conspicuity of markings
- Appearance
- Water spray
- Pavement strength
- Cracking
- Serviceability – particularly aging effects

Many of these failure parameters are inter-related; consider skid resistance and surface texture. A study by Roe and Hartshore (1998) (Sicoe, 2005) showed that surfacings with low levels of texture depth show clear trends to yield lower levels of surface friction.

2.7 Performance models

2.7.1 New Zealand performance specification

New Zealand engineers have developed a deterioration model that they use as a performance specification to quantitatively evaluate sprayed seal performance during its first year of design life. The specification can be referenced in appendix B.

Transit New Zealand (TNZ) use the performance specification TNZ P17 to evaluate new sprayed seals over their first 12 months. The philosophy behind the P/17 specification is that the texture depth after 12 months of service is the most accurate indication of the performance of a sprayed seal for its remaining life. The New Zealand specification also states that, 'the design life of a chip seal is reached when the texture depth drops below 0.9 mm on the road surface area supporting speeds greater than 70 km/h' (TNZ P17). The specification is founded on the assumption that long-term chip seal service life is determined by the consequence of texture loss due to flushing. The specification relies on two (2) models; the seal design life model and the texture depth deterioration model.

The Seal design life model shows a relationship between design life, ALD and traffic loading in equivalent light vehicles. The model used by the TNZ P17 specification is,

$$Y_d = 4.916 + 1.68ALD - (1.03 + 0.219ALD) \log elv$$

Where Y_d = design life of the seal

The texture depth deterioration model shows the relationship between the texture depth, ALD and the total traffic loading to date in equivalent light vehicles. The model is given by,

$$TD = k - B\ ALD \log (T)$$

Where TD = texture depth of seal

k = constant dependant on ALD and bitumen spray rate

B = factor describing the rate of change in texture depth with traffic loading. -0.07 has been adopted by TNZ.

T = total traffic loading to date in elv

The seal design life as determined through the seal design life model is used in the texture depth deterioration model to produce the relationship between the texture depth at one year and the seal performance. The relationship is given by,

$$TD_1 = 0.07\ ALD \log Y_d + 0.9$$

Where TD_1 = Texture depth measured one (1) year after construction

Y_d = design life as determined by the seal design life model

0.9 = suggested texture depth at the end of the design life

New Zealand contractors warrant their chip seals and must rectify a seal that fails the P/17 performance criteria at the one year mark. The construction contractors are paid based on two rates; square metre rate for design and construction of the seal, and the binder supply and spray rate for texture filling. The latter, binder, rate is payed based on the seal performance a year after construction. The payment is reduced by an amount proportional to the difference between the expected life and design life of the seal.

Gransberg (2007) used the New Zealand performance specification to evaluate U.S. chip seal performance. The specification was adapted and used successfully to predict premature failure of the chip seals in the U.S.

2.7.2 Austroads Reseal intervention model

Austroads has developed a reseal intervention model consisting of two parts:

- The first part determines the increase in bitumen viscosity with time based on the temperature and durability of the bitumen used
- The second part estimates the viscosity at which distress will occur based on the mean temperature. Austroads (2005b) found this model was less reliable than the bitumen hardening model and more data is required to improve its accuracy.

The Bitumen hardening model is a simple mathematical model that has been developed to describe the rate at which bitumen will harden. To calculate the bitumen hardening rate at a site, the following data is required:

- Yearly average of the daily maximum air temperature
- Yearly average of the daily minimum air temperature
- The ARRB durability test results for the bitumen

The distress viscosity model is a function of the yearly average of the daily minimum air temperature.

Austroads project AS1061 further developed the reseal intervention model by including a seal size term in the bitumen hardening model. Additionally, another aim of the project was to develop a spreadsheet tool to assist users of the model.

The model is only applicable to properly constructed seals in which the bitumen hardens though thermal oxidation only. The models precision only applies to points that lie within the range of the database used to construct it.

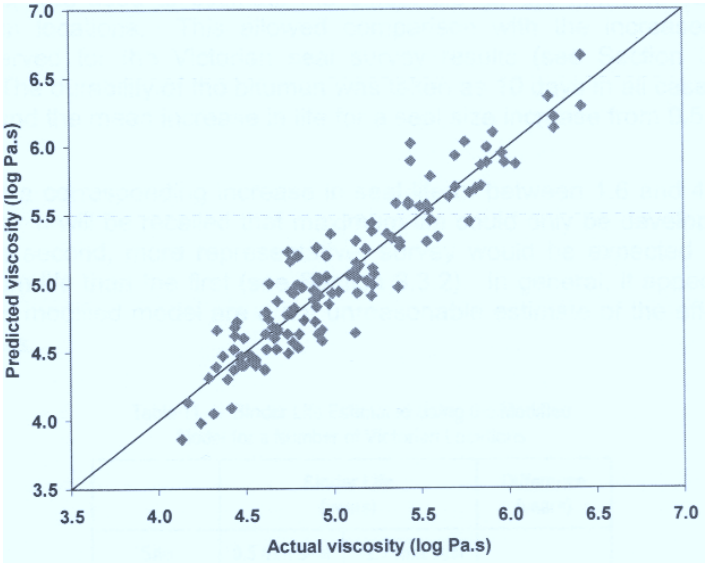

Figure 2-4 Precision of the Austroads model
Source: Austroads Research Report: AP-R271/05, page 19

Table 2-2 Austroads model Variable Range
Source: Austroads Research Report: AP-R271/05, page 20

Variable	Minimum	Maximum	Range
log η (Pa.s)	3.86	6.66	2.8
TMAX (°C)	19.5	30.1	10.6
TMIN (°C)	8.2	17	8.8
Durability	4.5	18	13.5
Y (years)	1	13.75	12.75
T (°C) (eqn 3)	13.85	23.55	9.7
S (mm)	10	20	10
Viscosity before spraying (Pa.s at 60°C)	94	228	134

Figure 2-4 shows the correlation between the actual bitumen viscosity and the viscosity predicted by the Austroads model. Table 2-2 lists the range of each variable for which the Austroads model will be accurate. Regions and roads of properties that fall outside of the range are outside the scope of the model.

Oliver (1990) suggests that the seal life prediction calculator is likely to be more precise than the prediction based on the pavement condition surveys. The reseal intervention model will ensure that the appropriate time to reseal a surface is before distress affects the integrity of the surface or underlying base.

2.8 Flushing

Flushing is perhaps, the most important distress mechanism since it has major safety implications and can necessitate intervention long before the expected life of a seal is reached. A reduction of skid resistance, often substantial, is likely to result with flushing.

Flushing is defined by Austroads as a pavement surface defect in which the binder nears the uppermost surface of aggregate particles and minimal surface texture (texture depth) exists. Bleeding is considered a more severe case of flushing, where the binder covers the aggregate particles completely.

A study performed by Gransberg (2007) on US chip seals found that the most common short term failure mode was loss of aggregate and the most common long-term failure mode was flushing. According to Gransberg (2005), the major reported long-term distress that appears in the American chip sealed roads is flushing.

There is some anecdotal evidence that there has been an increase in the number of bleeding seals observed around Australia in recent years.

2.8.1 Possible mechanisms

Austroads (2008b) gives three possible reasons as to why a seal becomes flushed are:

- Embedment of the sealing aggregate into the underlying substrate
- The aggregates in the seal, pack more tightly together than is assumed in the design process
- Aggregate physically degrades either through wear or breakdown

Embedment

The aggregate punches into the layer below, equivalent to reducing the ALD of the aggregate. Consider aggregate with an ALD of 7mm subject to embedment of 2mm, which results in a reduction of aggregate height of approximately 30%. The seal is designed so that the binder would be 2/3 the height of the ALD and would in fact have binder close to the surface of the aggregate after embedment.

It is less easy to conceive embedment would occur in the case of reseals since the layer underneath is constructed of aggregate held in place by a supposedly harden bitumen film. However, some circumstances may result in the softening of the bitumen, including

- Cutter or binder diffusing into the existing bitumen
- Application of a reseal on an existing seal where the binder had not hardened to the 'normal' reseal level.
- Where there is extensive patching

The last point is supported by a study of U.S. chip seals by Gransberg (2007) that found placing a new chip seal over a relatively new seal appeared to exacerbate a poor surface condition rather than fix it.

The degree of embedment relates to the grade (hardness) of the bitumen, number of heavy vehicles, vertical stresses applied by the wheels and the temperature of the surface when loading occurs. The study by Austroads (2008b) showed that embedment in the wheel paths were on average 1.2mm more than the embedment between the wheel paths.

Tighter packing of the surface aggregate

The Austroads seal design method assumes the aggregate rotates during construction rolling and early trafficking so that the least dimension is vertical. The method is verified by reference to on-road behaviour of seals. In general, the air void volume of the surface aggregate is approximately 25% greater than if every particle was packed closely and lay with its least dimension vertical.

The action of very heavy vehicles may result in the further rearrangement of aggregate resulting in a further reduction of air voids.

Factors that may exacerbate the process include:

- Overspreading of the aggregate
- Crushing of aggregate particles
- Attrition (grinding) of particles to remove asperities

Aggregate wear

Many tests are available to assess the wearing characteristics of aggregate. The application of these tests ensures that sealing aggregates are wear resistant, however, in some regions good quality aggregate is unavailable. The study by Austroads (2008a) showed disintegration of the aggregate resulted in many small particles in the seal that effectively reduced the ALD and displaced the binder.

2.8.2 Surface texture

Surface texture refers to the macrotexture of the pavement surface. Flushing of a seal will alter its surface texture, effectively reducing the texture depth as the flushing severity increases.

The surface texture is measured by the texture depth of a seal. The most common method of measurement is the sand patch test. The sand patch is a

volumetric technique for measuring the texture depth of a pavement's surface. The test method is specified by Austroads in AG:PT/T250.

According to Holtrop (n.d.), requests have been received to develop an alternative to the sand patch method of measuring surface texture, as a result of increased concern for the safety of the tester. A vehicle mounted laser profiler is recommended where operator safety and traffic delays are a concern. A report by Austroads (2008b) has found a correlation between the Mean Profile Depth (MPD) of the laser profiler and the Sand Patch Texture Depth (SPTD). The relationship is

SPTD = 2.5 MPD

At present, a method does not exist that can completely replace the current sand patch test in the seal design practice.

2.9 Evaluation systems

The rating system currently used in Australia is based on visual inspection and assessment using a standard rating for various criteria. The system is subjective and relies on the experience and skill of the observer. Given the nature of the rating it should be a fairly broad, simple, evaluation scale. AAPA (2009) states that a good indication of binder condition and performance of existing seals are provided by considering the following criteria:

- Loss of aggregate
- Amount and severity of cracking
- Amount of maintenance patching
- Binder level up the aggregate particles
- Texture of surface
- Bitumen hardening

Rating systems of different complexity have been examined in the past few years. However using a simple rating scheme allows quick decision to be made regarding reseal prioritisation. To give an indication of future funding requirements, a rolling re-seal program could be established.

2.10 Summary

Sprayed sealing works encompass many varying functions, all of which require thorough guidelines and design protocols to ensure the anticipated life is reached. Some sprayed seal applications are considered delicate and have a short design life. Other seals are more robust and are designed for a longer working life with more adverse conditions applied. This project will only consider seals coats, as these are subject to more defects considering the loading and long design life.

Many assumptions are made in the design of the coat seals. Such assumptions need to be made considering all conditions across Australia. In some regions, this leads to seals designed for conditions that are outside those assumed in the design guide.

The performance of a seal is seen as the 'Avoidance of certain failure parameters' (Robertson et al, c.1990) Milne et al. 2005, p3). However at some stage in the life of the seal it must fail. Austroads has developed a model to predict the life of a seal. The conditions of the Far North Region will need to be checked against the variable range of the model. The model only considered binder hardening and the associated distress, whereas another mode of distress may dictate the life of the seal.

The New Zealand performance specification requires the condition of the seal some time after its construction to predict the performance (life) of that seal. The New Zealand specification considers a seal to reach the end of its working life when the seal is at a certain texture depth. This model has an advantage over the Australian model as it uses 'real' results early in the life of the seal to predict its remaining life.

Currently seal performance is evaluated by visual inspection. Such an evaluation system is subjective and very much dependant on the individual performing the inspection.

It appears that the long term failure mode of seals across the world is flushing. This failure mode affects the safety of the roads by reducing the skid resistance and increasing the likelihood of aquaplaning. Due to the major safety implications, flushing is considered important to the Department of Main Road.

3 Methodology

3.1 Introduction

This project methodology will give an overview of the procedure employed to satisfactorily complete the research project in accordance with the project specification. The New Zealand TNZ P17 performance specification was selected to model the deterioration of sprayed seals in the Far North Queensland Region. The validity of the TNZ model must be checked prior to the application of the model to the road network. The validation of the models required the selection of seal property to be monitored, the collection of data for the selected study area and the analysis of the data.

3.2 Background information

The first phase of this project involved researching information pertaining to existing seal evaluation systems, seal defects and associated mechanisms and seal performance criteria. The information was sourced from university libraries, Main Roads' library, electronic databases and internet sources. The information pertaining to this project is found in the literature review chapter.

3.3 Seal properties

The selection of the seal properties to be assessed was based on the following factors:

- The associated failure of the seal property
- The effect the failure will have on the safety of the road users
- The effect the failure has on the life of the seal
- Mode of quantifying the seal property failure
- Whether the seal property is associated with any existing seal evaluation models

The above factors ensure that the seal property that was selected had a significant effect on safety and seal life. It was also important to select a seal property that was easily measurable and where data was readily available.

The texture depth was considered as the seal property to be assessed. The failure of this property is a reduction in texture depth to a level where the road surfacing is not safe. This failure is referred to as flushing and has great implications for road safety. Flushing is also the most common long-term failure in seals; therefore a premature occurrence would affect the seal life. There is anecdotal evidence that there is an increase of occurrences of flushed seals. Texture depth is easily and commonly measured; it is a key parameter for seal design, and yearly measurements are collated in the Main Roads ARMIS database. The New Zealand performance model (TNZ P17:2002) is reliant on the texture depth to predict the performance of a reseal. Based on these considerations texture depth was chosen to be assessed for this research project.

3.4 Study area selection

The Far North region network consists of roads of varying surfacing treatments, geometry and traffic loading. It was my intention to select roads in the region such as to limit the variables. This project only considered sprayed seals of C170 bitumen on roads where the geometry is flat. By only considering C170 bitumen seals in the analysis, would remove the variability the polymer modifiers in the bitumen may have on the life of the seal. Roads in hilly or undulating terrain encounter greater traffic loadings on the ascents due to the heavy vehicles travelling slower than they would on a flat section of road. Therefore the roads selected for study are constructed on flat terrain. Seven (7) roads were selected where the surface treatment is a sprayed seal and the geometry/terrain is flat.

Of these seven roads, only reseals were considered. This would further reduced the number of variables, as it may be conceived that the existing seal is impermeable and embedment may not contribute to a change in texture depth, provided the reseal was applied at or near the end of the seal design life. The roads selected for study have traffic volumes varying from 49091 to 261 AADT.

3.4.1 Bruce Highway 10N and 10P

The Bruce Highway is a national highway and is the major connection between the Queensland state capital, Brisbane, and Cairns in the Far North region. The Highway is approximately 1700Km long of which 234km is the responsibility of the Far North Region. Of all roads in the region, the Bruce Highway is subject to the greatest traffic loading. The majority of the highway within the region traverses flat coastal terrain, with the exception of the Cardwell range between Ingham and Innisfail, and sections of undulating terrain.

3.4.2 Captain Cook Highway 20A

The Captain Cook Highway is a coastal road connecting Cairns and Mossman. The road is approximately 75km long with similar traffic volumes to the Bruce Highway.

3.4.3 Palmerston Highway 21A

The Palmerston Highway connects the Atherton Tablelands to the Bruce Highway near Innisfail. A substantial portion of the road is in hilly/undulating terrain. The traffic volumes are relatively low; however have a large percentage of heavy vehicles due to the abundance of agricultural industry in the Atherton Tablelands and the quarry connected to the highway. This road was selected due to the large amount of sprayed seals applied to the highway.

3.4.4 Kennedy Highway 32A and 32B

The Kennedy Highway stretches from the Captain Cook Highway to the Palmerston Highway near Ravenshoe, in the Atherton Tablelands. Approximately 12km on the 32A section of Kennedy Highway is constructed on mountainous terrain.

3.4.5 Gulf Developmental Road 92B

The Gulf Developmental Road is an inland road with small traffic loadings. In contrast with the other roads selected for study, the Gulf Developmental Road has only had bitumen sprayed seals applied as a surfacing treatment.

Table3-1 State controlled roads in the study area

Road No	Road Name	Length (km)	AADT	% HV
10N	Bruce Highway (Ingham to Innisfail)	148.4	2784-12042	18.04
10P	Bruce Highway (Innisfail to Cairns)	85.5	5920-49091	11.39
20A	Captain Cook Highway	74.9	5396-39274	9.78
21A	Palmerston Highway	78.6	261-2201	17.89
32A	Kennedy Highway (Cairns to Mareeba)	48.9	4675-7608	10.41
32B	Kennedy Highway (Mareeba to Ravenshoe)	82.2	1031-10890	10.75
92B	Gulf Developmental Road	147.5	162	27.65
	Total:	666		

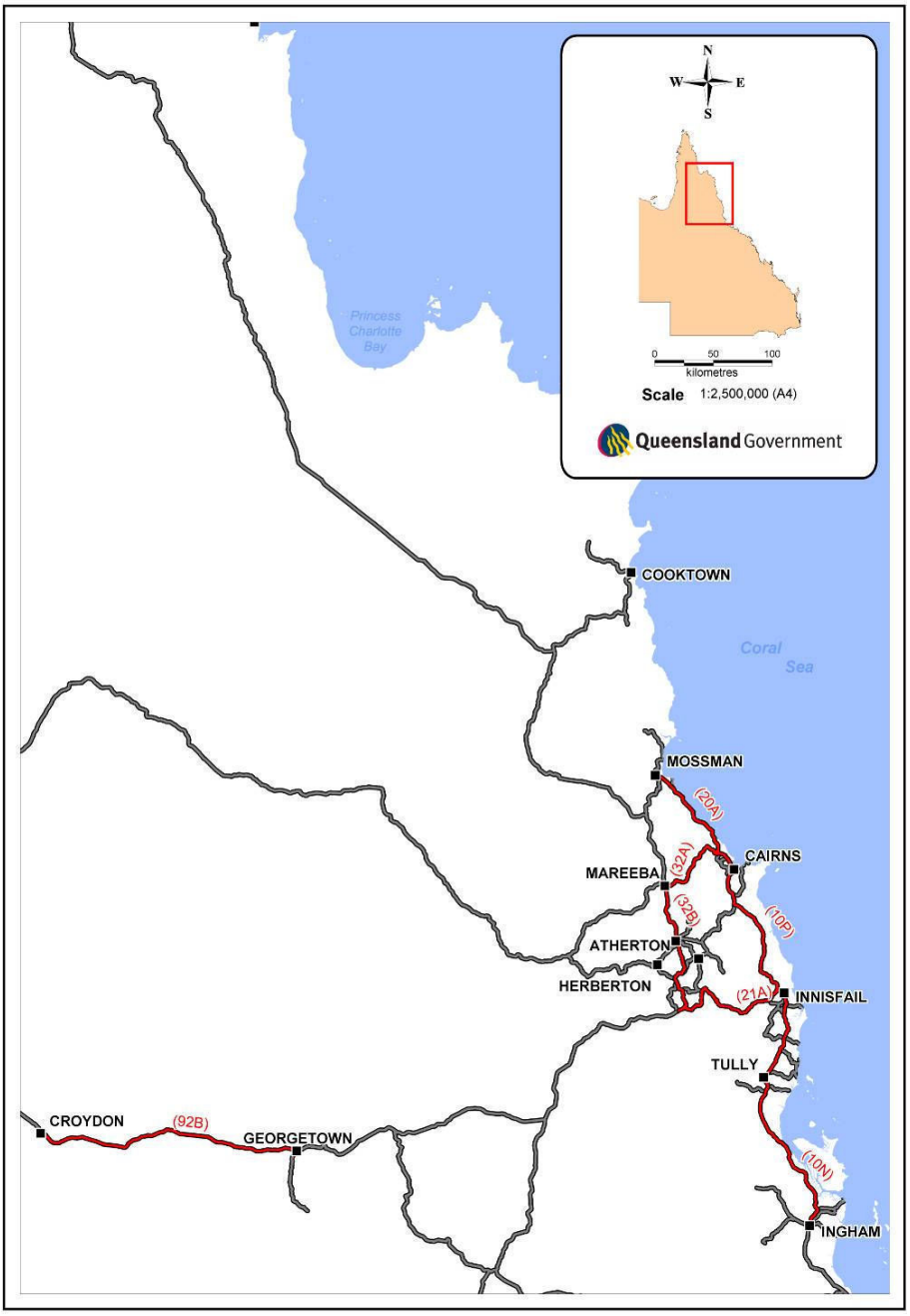

Figure 3-1 Map of the study area

3.5 Data collection

The ARMIS database is the greatest sources of seal data available for the region. The data was exported from ARMIS as an excel spreadsheet. For each road, two (2) data sets were required.

The first dataset (layer data) contained the age of each layer in the road including the pavement material. A spreadsheet for each road was constructed. For each layer on each section of road the following relevant data was outputted directly from ARMIS:

- Chainage – start and finish for the section of road
- Layer number – with 1 being the top layer
- Layer depth – for seal and reseals this corresponded to the nominal aggregate size used
- Layer date – the date the layer was constructed
- Layer type name – describe the layer type. i.e. bitumen sprayed seal
- AADT – added manually
- Percentage of heavy vehicles – added manually
- Number of lanes – added manually

Other data was outputted from ARMIS, such as Main Roads region number, but this did not contribute to the project. The data was sorted by road section and then by layer number. This data set contained over 11,000 data points for the seven (7) roads.

The second dataset (texture depth data) from ARMIS was the yearly sensor measured texture depths from 2001 to 2007 for each section of road. Some sections of road were missing texture depth data for certain years.

3.6 Data Manipulation

3.61 Layer Dataset

This dataset was used to find the mean seal life for each nominal seal size for the seven roads selected. The data points of relevance were those only relating to bitumen sprayed seals.

A Matlab program (sealage.m) was developed to sort and collate all the relevant data from the dataset, refer to Appendix C for program code script. The program imported all the data from layer dataset, which consisted of seven spreadsheets. The layer data for each section of road corresponded to only bitumen spray seals was extracted from the dataset. Each corresponding layer was compared to the next layer for the same section of road to calculate the seal age. The age of the seal was determined by subtracting the layer date from the proceeding layer date. The vehicles per lane per day (v/l/d) were determined by dividing the AADT by the number of lanes, assuming all lanes were equally trafficked. AADT at the time of completion of the seal was determined by assuming a constant growth in traffic volumes of 2.5% per annum. This procedure was repeated for all of the selected roads.

The first output of the program was an excel spreadsheet (SealAge.xls) containing the following data for only bitumen spray seals:

- Seal age
- Nominal seal size
- Adjusted AADT
- v/l/d
- Percent of heavy vehicles

Further data was extrapolated, such as:

- Equivalent light vehicles
- TNZ P17 Life prediction

The data was sorted by nominal seal size and then by seal age.

The second output was an excel spreadsheet (SealPos.xls) containing the following data:

- Road code
- Chainages
- Construction date

This data is used in conjunction with texture depth dataset to monitor the change in yearly texture depth. The output was restricted to seals constructed after the 1st January 2000, as ARMIS did not contain texture depth data prior to 2001.

3.6.2 Texture Depth Dataset

The sensor measured texture depth was converted to the sand patch texture depth value by the following relationship.

SPTD=2.5(MPD)

A Matlab program (tdreg.m) was developed to manipulate texture depth dataset. The data was sorted for each section of road containing a bitumen spray seal from 2001 to 2007. The program imported the data from the SealPos dataset and determined the sections of road for which relevant data existed. The sections of road were cross referenced with the texture depth dataset and the data was outputted as a graph detailing the yearly texture depth over the section of road. Each of the 44 graphs contains the yearly measured texture depth and the average yearly texture depth over the section of road. The yearly texture depth data for the 44 sites were collated and output as a spreadsheet (SealTD.xls).

The texture depth dataset was further manipulated to compare the change in texture depth predicted by the TNZ P17 deterioration model. The predicted texture depth was calculated from the data in SealTD dataset. The MATLAB program (tdrdeg.m) imported the data from SealTD.xls and plotted the average measured texture depth and TNZ P17 predicted texture depth against the age of the seal.

3.7 Validation of Deterioration Model

The validity of the TNZ P17 deterioration model for the Far North region was check by comparing the predicted life and actual life of a seal, as determined from the manipulation of the Layer dataset 1. A graph for each nominal seal size showing the correlation was generated.

The model was further tested by comparing the deterioration of texture depth of a seal over the period of 2001 to 2007 with that predicted by the model.

3.8 Development of the Far North Region Seal Life Model

The seal life model would be manipulated to reflect the seal behaviour in the Far North Region. The TNZ P17 performance specification uses the following relationship between traffic loading (elv), sealing aggregate (ALD) and seal life (Y_d).

$$Y_d = 4.916 + 1.68ALD - (1.03 + 0.219ALD) \log elv$$

Where the term

$4.916 + 1.68ALD$;

represents the effect the aggregate has on the seal life and will be referred to as the aggregate-life term.

Similarly the term

1.03 +0.219ALD;

represents the effect the aggregate has on the rate of deterioration and will be referred to as the aggregate-deterioration term. These two (2) terms are adjusted so that the deterioration model reflects the seal behaviour in the Far North Region.

Using the real data from seal age dataset, a logarithmic trend is fitted to the plot of seal life versus log elv for each aggregate ALD. This graph is used to calculate the aggregate-life and aggregate-deterioration terms for the region. The ALD of the aggregate is not readily available and is therefore assumed to be 60% of the nominal aggregate size. The reduction factor is that used by sprayed seal designers in the Far North Region for preliminary seal designs where the aggregate properties are not known.

The aggregate-life term is calculated by firstly, extrapolating the seal life for each ALD value when elv is 1; then by plotting the seal life against ALD and determining the relationship.

The aggregate-deterioration term is calculated by determining the rate of deterioration for each ALD value and plotting the rate of change against ALD.

4 Results & Analysis

4.1 Introduction

The TNZ P17 deterioration model was selected to assess the performance of sprayed seals in the Far North Region. The successful application of this model requires the validation as assessed against actual seal behaviour.

4.2 Validation of Model

4.2.1 Seal Life

For each nominal aggregate size, the ages of the sprayed seals (Blue) were plotted against a logarithmic scale of Vehicle/Lane/Day (in equivalent light vehicles). A line was fitted (Black) and compared to The TNZ seal life prediction (Pink). The equation for the line of best fit is located in the top right corner of the graph. The region seal life predication (Yellow) has been retrofitted to the graph. Refer to graphs 4-1 to 4-4.

The range of seal ages show no clear trends with regard to the change of seal life as a function of traffic loading. Any correlation between the trend line and the TNZ prediction may only be considered coincidental. The data does however show some localised trends, such as diagonal lines of data points. These localised trends are formed by many seals of different ages on a section of road with a constant traffic loading. Consider the AADT is affected by a growth factor of 2.5% per annum, where the traffic loading on an old seal will be less than the loading on a new seal. The line of data points is diagonal, suggesting that the reseals on the section of the road are being replaced sooner than they were in the previous years. This observation reinforces the concerns raised by DTMR regarding seal lives in recent years.

The wide and seemingly random range of seal ages may be due to a number of factors. Low seal age may be due to primer seals incorrectly identified as seals, incorrect input of chainages and premature failure of the seal. Primer seals have a design life of approximately two (2) years and the incorrect identification as a seal would yield a low seal age. The incorrect input of chainages for a new reseal may reduce the recorded seal life of adjacent seals. Consider a seal constructed three (3) years prior to a reseal on an adjacent section of road. The chainage of the new reseal is recorded such that it was applied to the adjacent section of road. The adjacent seal is recorded as having a seal life of three (3) years, when in fact the seal layer will continue to age. This problem would also conversely effect the seal age of the section of the road where the reseal is applied, resulting in a seal age greater than it should be. The omission of new seals in ARMIS would also result in high seal age data.

Regardless of the inconclusive correlation between the regional seal age and TNZ seal life prediction, the region data and trends will be used for further analysis and manipulate the deterioration model.

7mm Seal Age

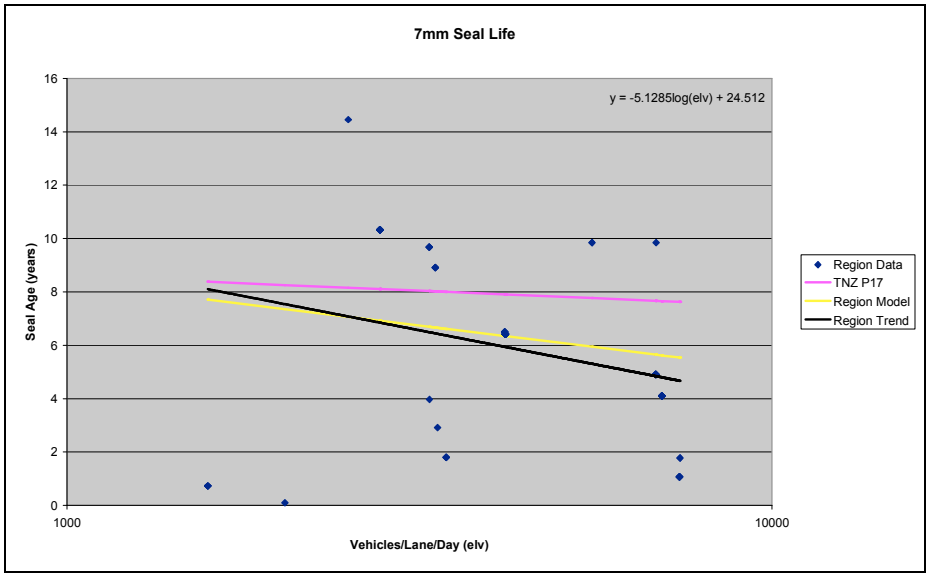

Figure 4-1 7mm seal age in far north region

There is less seal age data available for 7mm seals than the other sizes. The range of 7mm data is between 1600 and 7400 with an even distribution of data points. The trend line fitted to the data shows a greater rate of seal life deterioration than the TNZ prediction. Over the range of data the trend, region model and TNZ model all predict a similar seal life of approximately eight (8) years at 1600 v/l/d. There is some divergence between the three lines at the upper limit of the range, with the TNZ model, region model and data trend predicting seal lives of 7.6, 5.5 and 4.7 years at 7400 v/l/d, respectively. The 7mm trend line is defined by the following equation,

$y = -5.1285 \log(elv) + 24.512$.

Over the range of data, the region model shows some similarities to the trend.

10mm Seal Age

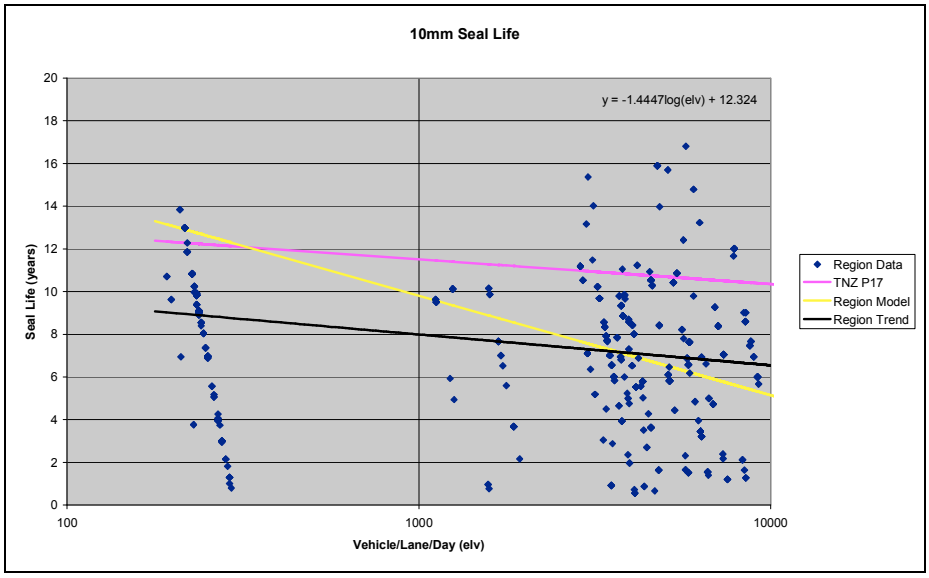

Figure 4-2 10mm seal age in far north region

The majority of reseals in the Far North region are 10mm seals. The seal age data available for the 10mm seal is across a wide range of traffic loading, from 200 to 13500 v\l\d. The data is concentrated in two sections, around 250 v/l/d and 3000-9000 v/l/d. The data grouping around 250 v/l/d are seals on the Gulf Developmental Road. The trend line fitted to the 10mm seal age data is approximately four (4) years below the TNZ prediction and follows similar seal deterioration. The 10mm trend line is defined by the following equation,

$y = -1.4447 \log(elv) + 12.324$.

The region model predicts greater seal life deterioration than that of the region trend and TNZ model.

14mm Seal Age

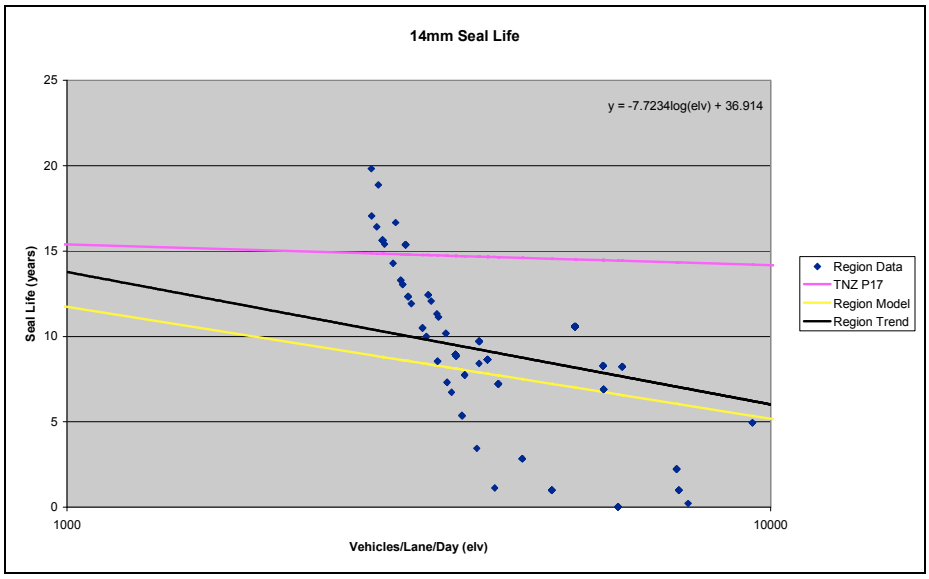

Figure 4-3 14mm seal age in far north region

The seal age data available for the 14mm seal ranges from 2700 to 9400 v\l\d. The data suggests that 14mm reseals are used on medium to high traffic volume roads. The region trend line fitted to the seal age data and the region model predict greater seal life deterioration than the TNZ model. The 14mm trend line is defines by the following equation,

$y = -7.7234 \log(elv) + 36.914$.

16mm Seal Age

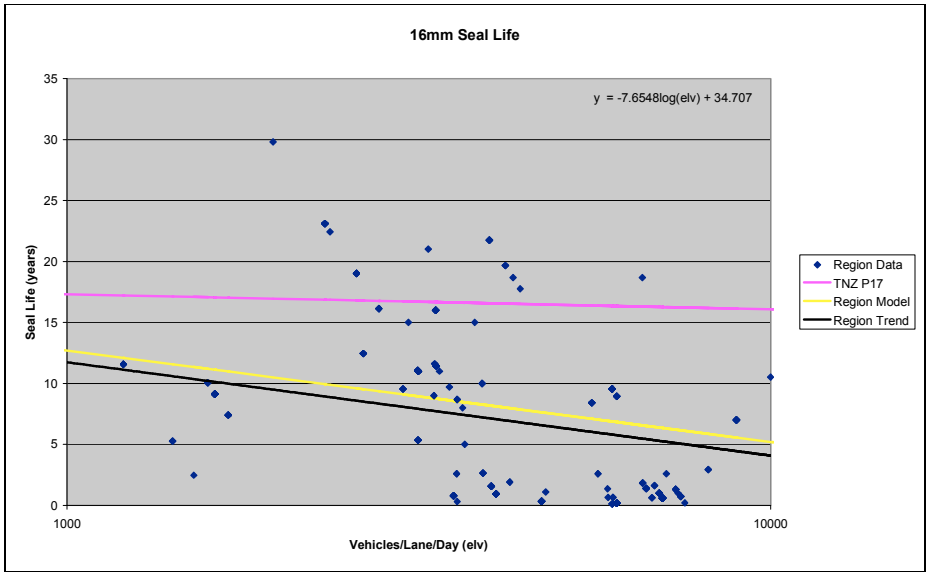

Figure 4-4 16mm seal age in far north region

The greatest range of seal age data exists for the 16mm seal, from 250 to 13700 v\l\d. The region trend line fitted to the seal age data and the region model, predict a greater seal life deterioration than the TNZ model. The 16mm trend line is defined by the following equation,

y = -7.6548 log(elv) + 34.707.

4.2.2 Texture depth deterioration

The TNZ P17 specification states the relationship,

TD = k -0.07 ALD log (T),

which represents the deterioration of texture depth over the life of the seal. The specification also states that the seal is at the end of its life when the texture depth reaches 0.9mm. This condition gives:

0.9 = k – 0.07 ALD log (T)

where T is the traffic loading and is represented by:

$T = (elv\ 365\ Y)$

The traffic loading is the number of equivalent light vehicles travelling on the seal for a period of Y years. When the texture depth is 0.9 mm the Y variable is the seal design life calculated by the seal life model and is represented by Yd. The combination of these equations yields:

$TD_Y = 0.07\ ALD \log (Yd/Y) + 0.9.$

This equation is used to predict the texture depth of a seal at any point in its design life and will be used to compare the actual and predicted texture depths. Notice the constant, k, has been cancelled out and therefore it is not necessary to specify its value.

For each seal in the study area constructed after the year 2000, the texture depth was compared to the prediction by the TNZ texture depth model. Figure 4-5 shows the measured (blue) and predicted (Red) texture depth plotted against seal age.

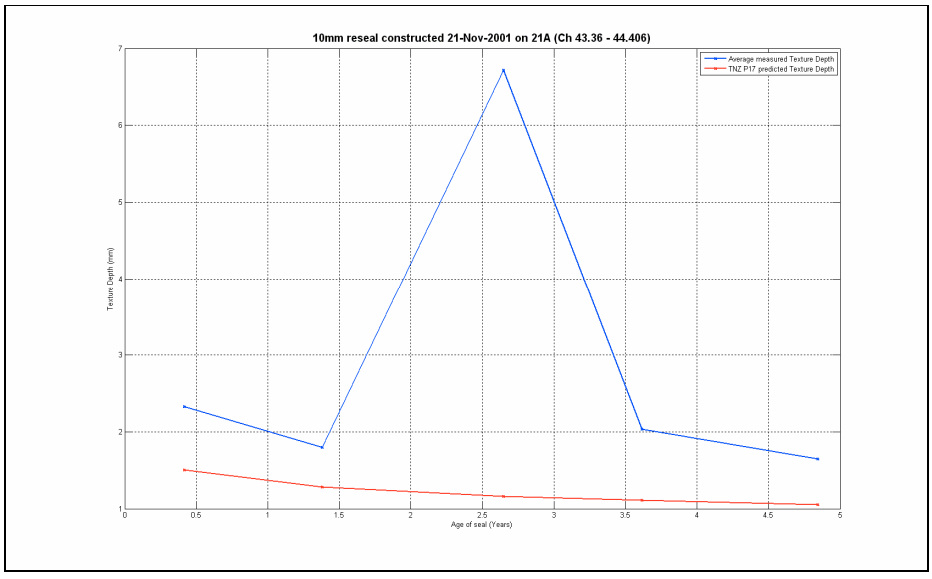

Figure 4-5 Texture depth deterioration of a 10mm seal on 21A in Far North Region

The measured texture depth in figure 4-5 does not follow the TNZ prediction, with a significant increase in texture depth recorded 2.6 years into the life of the seal. To better understand the anomaly the yearly texture depths over the section of road must be analysed. Figure 4-6 shows the yearly texture depths in the outer wheel paths over the section of road.

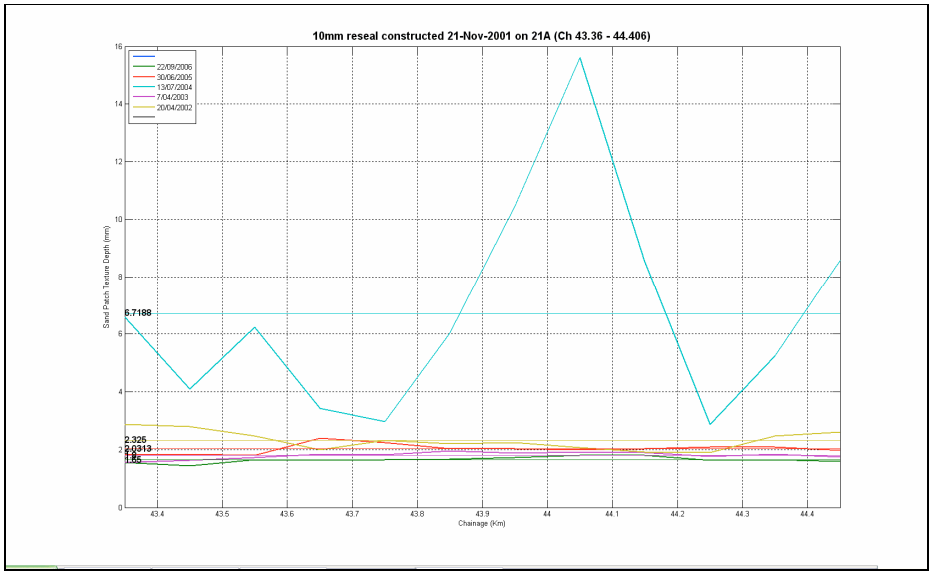

Figure 4-6 Yearly texture depth of a 10mm seal on 21A in Far North Region

The graph shows that the texture depth over the entire section of road measured on 13 July 2004 is significantly greater than the other years, including the preceding years when it is expected that the texture depth would be greater. The largest peak for 2004 is 15.6mm located at chainage 44.05km. This is clear evidence of inaccurate texture depth data, as the maximum texture depth on a 10mm seal would be less than 10mm. Further investigation of the texture depth data revealed that the peak of 15.6mm had a standard deviation 13.55mm over a 100m section of road. In some cases sections of seal had texture depths of 2mm with a standard deviation of 13mm. This was representative of many sections of road over all of the recorded years.

The inaccurate texture depth results may be due to the nature of measurement employed. The texture depths are sensor measured and averaged over a 100m section of road along the outer wheel path, inner wheel path and between the wheel paths. The sensor is mobile and it is possible that over the 100m section the following factors may have affected the average texture depth:

- Pot hole patching – surface of different texture depth
- The sensor measuring adjacent sections along the width of the road
- Bleeding or stripping - significant variation of texture depth over the 100m section of road

The texture depth data does not accurately represent what is actually happening to the seal and cannot be used to validate the TNZ texture depth model.

4.3 Far North Region Seal Life Model

The TNZ P17 deterioration model accurately predicts the seal life of New Zealand Roads as a function of traffic loading and the ALD of the aggregate. A model must be developed for the Far North region that will represent the seal behaviour in the region.

The seal life model for the Far North Region is able to be developed using the seal age analysis from each seal size. The results from the regional seal age analysis yielded the following trend equations in the form of y = mx+c.

Table 4-2 Seal age analysis as a function of traffic loading

Seal Size (mm)	Trend Equation (y=mx+c)
7 mm	y = -5.1285 log(elv) + 24.512
10 mm	y = -1.4447 log(elv) + 12.324
14 mm	y = -7.7234 log(elv) + 36.914
16 mm	y = -7.6548 log(elv) + 34.707

The last term (c) in each equation represents the maximum design life of a seal of a given size. In the context of the model, the term represents the seal life if the road is subject to one equivalent light vehicle over the life of the seal. These values are used to determine the aggregate-life term in the Far North Region Seal life model. The values are plotted against the corresponding ALD to produce figure 4-7. The relationship as a function of ALD produced the aggregate-life term for the Far North Region model. The aggregate-life term for the region model is

3.1645 ALD + 4.8044

And represents the effect the ALD of the aggregate has on the seal life.

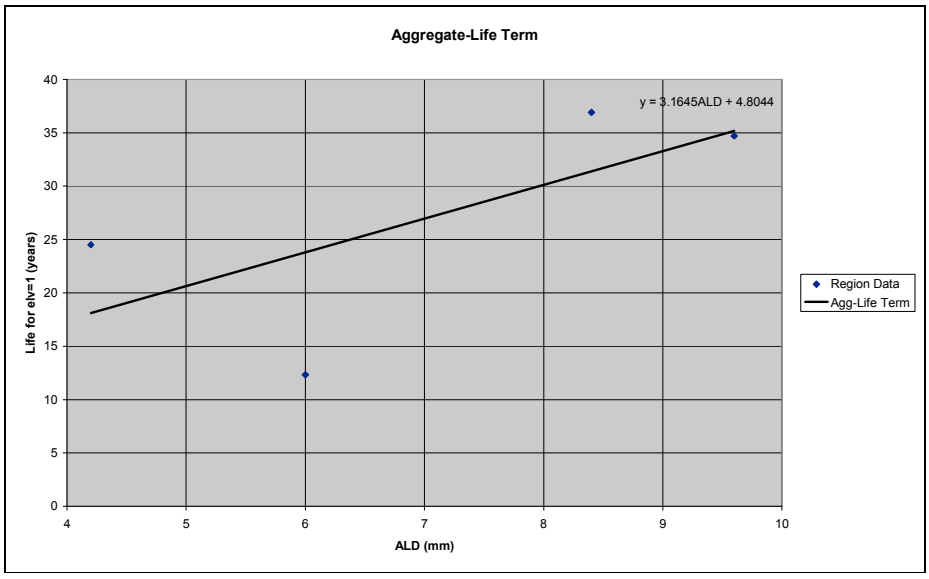

Figure 4-7 Maximum seal life as a function of ALD

The first term (m) in each equation in table 4-2 represents the rate of deterioration of seal life as a logarithmic function of traffic loading for each aggregate size. These values are used to determine the aggregate-deterioration term in the Far North Region Seal Life Model. The values are plotted against the corresponding ALD to produce figure 4-8. The relationship as a function of ALD produced the aggregate-deterioration term for the Far North Region model.

The aggregate-deterioration term for the region model is

0.7871 ALD - 0.061

And represents the effect the ALD of the aggregate has on the seal life.

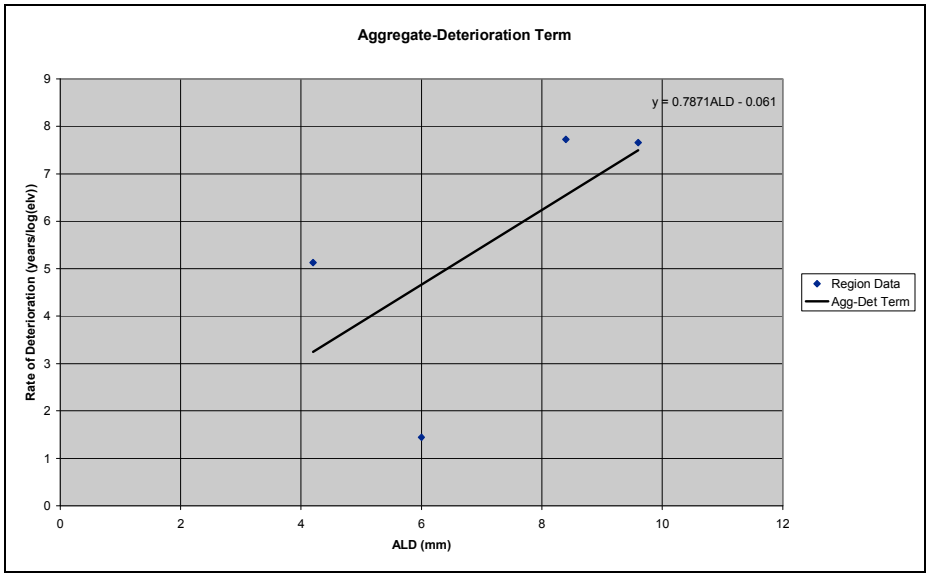

Figure 4-8 Rate of deterioration of seal life as a function of ALD

The combination of the aggregate-life term and the aggregate-deterioration term produces the seal life model. The Far North Region Seal Life model is defined by

$Y_d = 3.1645\ ALD + 4.8044 - (0.7871\ ALD - 0.061)\ Log(elv)$

Figure 4-9 graphically represents the behaviour of sprayed seals in the Far North region predicted by the seal life model. The graph shows a convergence of seal life near 10,000 v/l/d towards five (5) years. This would indicate that all seals regardless of aggregate ALD with have the same life on a road subject to 10,000 v/l/d (elv).

The accuracy of the model may be observed on the seal age graphs. The Yellow line represents the Far North region seal life prediction. With the exception of the 10mm seal age data, the Far North region model fits the trends closer than the TNZ model.

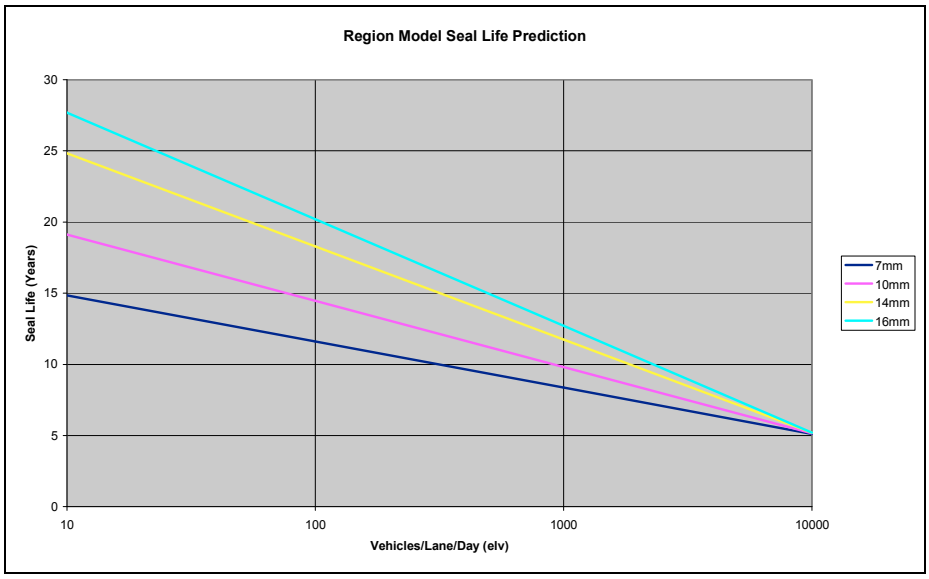

Figure 4-9 Far North Region seal life prediction

Figure 4-10 graphically represents the TNZ model. In comparison to the Far North region model it can be seen that the Region model predicts longer seal lives for small traffic loading, and a greater deterioration than that predicted by the TNZ model.

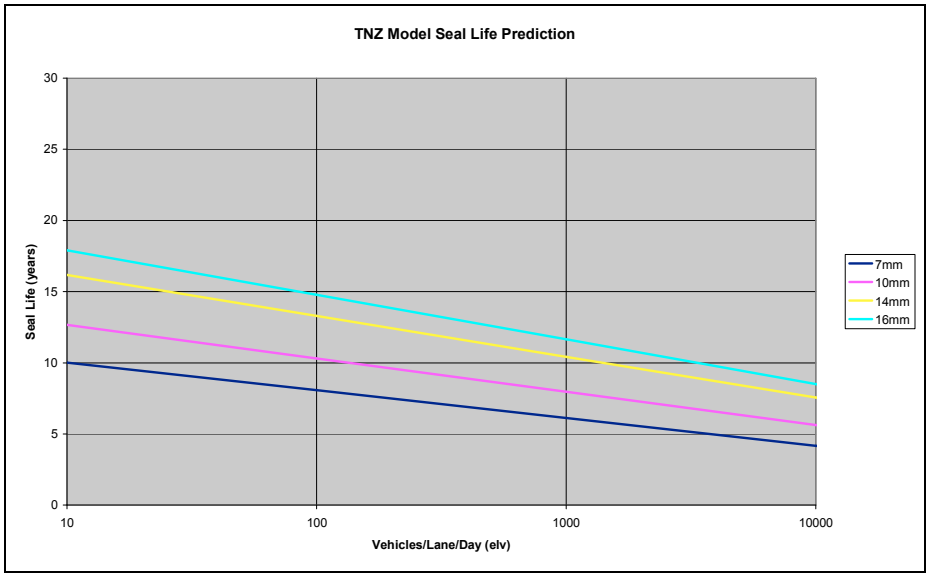

Figure 4-10 TNZ seal life prediction

5 Conclusion

The Department of Transport and Main Roads, Queensland, recognises that the assessment, prediction and monitoring of seal performance are vital for delivering continually high standard sprayed seals on the state roads. Anecdotal evidence suggests that more sprayed seals are failing prematurely due to flushing.

Premature flushing of seals is a global problem. Flushing is characterised by excess bitumen on the surface of roads, where the binder nears the uppermost surface of the aggregate particles. Bitumen is a crude oil based product and there are concerns for its future availability. Therefore, every attempt should be made to ensure that sprayed seals are reaching the design life. Most importantly, flushing has major safety implications. Poor skid resistance, inconspicuity of road markings and the propensity to aquaplane are among the most detrimental products of flushing. There is therefore an increased propensity for road crashes on roads with flushed seals.

The TNZ P17 performance based specification for reseals is viable tool for the assessment, prediction and monitoring of seal performance with respect to flushing. The design life and the texture depth deterioration models are detailed in the specification. The specification has already had success being implemented in New Zealand and America. The implementation of this specification ensures that the seal construction contractors are accountable for premature failure of sprayed seals. As a result, the process has lead to innovation in the delivery of sprayed seal.

The models detailed in the TNZ P17 performance specification have been used as a basis for developing models for the Far North region. A seal design life model was developed by using Data from ARMIS, the main repository for road related data held by the department. The Far North region seal life model is:

$$Y_d = 3.1645\ ALD + 4.8044 - (0.7871\ ALD - 0.061)\ Log(elv)$$

The seal age data collected for the Far North region did not show any clear trends and any correlation with the Far North region design life model could only be considered coincidental. The Far North region design life model requires more extensive and refined data to better develop the model.

The validation of the texture depth deterioration model was futile as the available texture depth data was inconsistent and inaccurate. As a result, the means by which the yearly texture depth data is collected requires review.

5.1 Project Benefits

The seal design life model developed for the Far North region is the first step required to adopt the TNZ P17 performance specification. It is suspected that the Far North region seal design life model does not represent the seal behaviour in the region. However, with more refined seal age data the model will be able to be refined and the TNZ P17 performance specification applied to the region. The employment of the performance specification is expected to have the same success as it has had in New Zealand and America.

The process used to develop the seal design life model detailed by this project can be easily applied in any region of the world.

The implementation of the TNZ P17 performance specification would ensure that the premature failure, with respect to flushing, would be predicted and remedial action planned long before the seal fails.

5.2 Future works

The Far North region design life model requires more exact data, to further develop the model. A testing program needs to be developed to collect texture depth data over the life of seals. The TNZ P17 specification predicts the performance of the seal, based on the sand patch texture depth performed after 12 months from construction. The predictions based on the data from the 12 month sand patch texture depths collected are inconclusive for the Far North region. Data over the entire life of a seal is required to check the validity of the TNZ P17 texture depth deterioration model.

The mandatory sand patch texture depths used for design can be used to check the current performance of the seal. For example, the design life of the seal is 12 years, therefore the texture depth after 8 years should be 1.2mm and testing shows a texture depth of 1.4mm. From this observation, two inferences can be made; the model is typical and the seal is performing abnormally, or the seal is typical and the model requires some adjustment. Thus, results from a large number of tested seals are required to determine the trend.

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Appendices

Appendix A Project Specification

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Andrew Jonathan ARMSTRONG**

TOPIC: SEALING WORKS PERFORMANCE STUDY

SUPERVISORS: Assoc Prof Ron Ayers, University of Southern Queensland
Mr Don Wallace, Dept of Main Roads

SPONSORSHIP: Department of Main Roads, Far North Region

PROJECT AIM: To develop and implement an evaluation system to ensure effective investigation, design, application and evaluation of bitumen seals.

PROGRAMME: Issue A, 19 March 2009

1. Research existing seal evaluation systems, seal defects and associated mechanisms, seal performance criteria testing methods and seal design rationale.
2. Decide which seal properties to evaluate eg. Skid Resistance, Texture depth etc.
3. Develop and document a system that will evaluate as-constructed sealed works properties against the properties predicted by design.
4. Select a suitable geographical area in which to implement a trial of the evaluation procedure.
5. Carry out the trial study, identifying sealed works suitable for model. eg. re-seal works, analysing the sealed works (design and as-constructed) and correlating between design and as-built seal properties.
6. After analysing the results of the trial study, carry out any necessary modifications to the proposed evaluation system.
7. Report on the results of the project in the required oral and written formats.

As time permits:

8. Develop testing plan to be used on future sealed works.
9. Assess other sealed works for further modelling.

AGREED: _____(student) Date: / /

_____(USQ supervisor) Date: / /

_____(MR supervisor) Date: / /

Examiner/Co-examiner:_____

Appendix B TNZ P17 Specification

TNZ P17:2002

PERFORMANCE BASED SPECIFICATION FOR RESEALS

1. SCOPE

This specification sets out the performance requirements for:

- single coat reseals using sealing chip with an average dimension greater than 5.5 mm;
- multilayer seals using sealing chips in the range of grade 2 to grade 6, as defined in TNZ M/6 Specification. This includes both wet and dry locking coats; and
- texturising seals and void fills.

The requirements are based on the presumption that the site is acceptable for resealing. Provision is made for the Contractor and Consultant to agree alternative acceptance criteria where site conditions are such that the design life is unlikely to be obtained.

2. TRAFFIC VOLUMES

The traffic volumes given in the schedule to this contract are to be used as the basis of tendering. A distinction is made in the AADT column of Schedule A between reliable estimates based on known data and less accurate data.

3. QUALITY PLAN

The Contractor shall submit to the Engineer for acceptance a Quality Plan detailing the procedures to be followed to ensure compliance.

The Engineer shall prepare a performance criteria report detailing each site resealed and forward to the Contractor within 20 working days after the final compliance assessment period.

4. SITE ACCEPTANCE

The Contractor shall inspect each site and consider whether the treatment specified by the consultant is appropriate for the site and whether all pre-seals repairs are satisfactory.

4.1 Confirmation of Treatment

In particular, the Contractor shall satisfy him or herself that the proposed treatment specified by the Consultant is appropriate for the site conditions based on the surface hardness, texture variation and traffic stress as detailed below for single coat and multilayer seals. For texturising and void fills the Contractor shall satisfy him or her self that the specified chip size is appropriate.

4.2 Surface Hardness

It is the Contractor's responsibility to satisfy him or herself that the hardness of the surface to be sealed is consistent. Where areas are found, that differ from the average of the rest of the site, then either:

If nominal (1 mm):

- an appropriate treatment may be agreed as a variation to the contract; or
- the acceptance criteria (which may not be in compliance with Table 1 of this specification) for the soft areas may be varied by agreement.
- In cases of dispute, the RTA “Ball Penetration Test Method” can be used. When tested by the RTA "Ball Penetration Test Method" T271 hardness test or equivalent, areas that have ball penetration values that are greater than 1 mm from the average of the rest of the site may be handled as follows:

If the average hardness of five randomly located positions over the area to be sealed is greater than 5 mm, then the Engineer may:

- allow an alternative sealing system and acceptance criteria; or
- the Engineer may instruct that the specified treatment shall be performed in accordance with the TNZ P/4 Specification.

4.3 Surface Texture

It is the Contractor's responsibility to ensure that the surface texture variation of the site is acceptable for the chip size to be used. If there are any areas where the texture variation is outside the guidelines stated in the Transit New Zealand (Transit) Bituminous Sealing Manual the Engineer shall be notified a minimum of seven days before sealing. If it is agreed that the surface texture variations are outside the stated guidelines, then either:

- an appropriate treatment shall be agreed as a variation to the contract; or

- the acceptance criteria (which may not be in compliance with Table 1 of this specification) shall be agreed; or

- the Engineer shall instruct that the specified treatment shall be performed in accordance with the TNZ P/4 Specification.

4.4 Traffic Stress

Where the Contractor considers that the traffic stress level renders the specified treatment inappropriate he may notify the Engineer. This notification shall be a minimum of seven days prior to construction. The Engineer shall either:

- agree with the Contractor appropriate acceptance criteria for each section ("section" is defined in clause 9.1 of this specification); or

- allow an alternative sealing system as a variation to the contract with agreed acceptance criteria; or

- instruct that the specified treatment shall be performed in accordance with the TNZ P/4 Specification in which case the payment for the section shall be at the tendered square metre rate reduced by 15%.

4.5 Payment Reduction

If the site does not comply with the hardness criteria or if the texture is outside the limits for the specified chip size, and the Engineer instructs that the specified treatment shall be performed in accordance with the TNZ P/4 Specification, then there shall be no reduction in payment.

4.6 Acceptance of Treatment

If the treatment proposed by the Consultant is considered appropriate by the Contractor then the Contractor shall agree the treatment and accept the site.

5. WORKMANSHIP

The sealing shall be performed in a workman-like manner with clean straight edges and all road furniture protected from spray. All surplus and waste material must be removed before the site is opened to unrestricted traffic. All surplus chips must be uplifted and removed from the works. Unless agreed by the Engineer no chip shall be swept across the shoulder. All surplus chips shall be removed from areas adjacent to the carriageways such as footpaths, accessways, business frontages and side roads.

RPMs shall be protected from spray for voidfills and texurisers, and removed for other seals.

6. TRAFFIC CONTROL

At all times during the construction of the works included in this specification, the Contractor shall take responsibility to ensure all traffic control is carried out in accordance with the specific contract requirements

Temporary traffic control restrictions shall not exceed 5 km in length at any one time unless approved by the Engineer in writing.

7. PERFORMANCE REQUIREMENTS

Throughout the maintenance period the whole sealed area shall have:

- For single coat seals and void fills; a uniform single retained layer of chips.
- For multilayer seals; a uniform double retained layer of chips with the second chip fitting inside the interstices of the chip used for the first layer.
- For texturising seals; a texture uniform enough to comply with the requirements of the Bituminous Sealing Manual for applying reseals.
- A texture depth sufficient to achieve the specified design life.

There shall be no obvious defects related to poorly constructed longitudinal or transverse joints, blocked spray nozzles or any other construction fault. The finished sealed surface shall not have any areas of obvious flushing, significant chip loss or loose chip.

After the speed restriction signs are removed the surface shall be regularly maintained during the maintenance period, so that:

- No more than 50 loose chips are left on any 2 m^2 area of the sealed carriageway for all chip sizes except for grade 5.
- No more than 100 loose chips are left on any 2 m^2 area of the sealed carriageway for grade 5.

At all times there shall be no windrow of chip either on the sealed surface or shoulder that could constitute a traffic hazard. All surplus chip shall be uplifted and removed from the works. Unless agreed by the Engineer no surplus chip shall be swept across the shoulder.

The seal shall comply with the requirements of Table 1.

The Contractor shall have available for inspection by the Engineer all documents detailed in the Quality Plan.

8. ACCEPTANCE TESTING

8.1 Accreditation

All material sampling and testing shall be performed by a laboratory which holds either accreditation by International Accreditation New Zealand or registration to ISO Guide 25:1990 for the specified tests, or alternative certification as accepted by the Engineer.

8.2 Aggregate Properties

The Contractor shall demonstrate, through quality records, that the aggregate properties comply with this specification. It is expected that testing frequency shall be in accordance with the New Zealand Pavement and Bitumen Contractors' Association Guidelines "Quality Assurance of Aggregates for Chipseals and Bituminous Mixes" BCA 9805 for source properties. The tests to determine the chip size shall be performed on stockpiles of chip that are proposed to be used on this contract. Each stockpile of chip shall be tested at the minimum frequencies stated in Table 2.

TABLE 2

Stockpile Size	Minimum Samples
< 100 m^3	1
100 - 500m^3	2
> 500 m^3	3

For sealing chips with an Average Least Dimension (ALD) greater than 5.5 mm where the mean ALD of different stockpiles varies by more than 0.5 mm, then the Contractor shall control the chip delivery such that there is a clear delineation on the finished seal between chips from different stockpiles. Chips outside the above criteria shall not be used on the same section of seal length.

8.3 Bituminous Binder Properties

Bitumen used shall comply with TNZ M/1 Specification and be the grade as detailed in Schedule A. The Contractor shall demonstrate, through quality records, that the bitumen penetration value is within the grade tolerances and that there are no added diluents in the bulk supply.

Where a flux is specified, it shall be Automotive Gas Oil (AGO) complying with TNZ M/1 Specification. Assurance of the correct quantity shall be detailed in the quality records.

Where a polymer modified binder is used, a minimum softening point shall be specified.

Where a minimum Softening Point has been specified for a polymer modified binder then the binder shall have a softening point greater than that specified, when containing 20% of the added diluent, according to ASTM D36.

TABLE 1: Reseal Performance Criteria

Performance Requirement	Criteria	Measurement	Test Method	When Measured*	Value
Safety	Skid resistance	Aggregate PSV Aggregate % crushed Texture depth	NZS 4407, Test 3.14 TNZ T/3	C C I**	As specified in Schedule A 98% minimum of particles with two or more broken faces 1.0 mm minimum
	Light reflectance	Texture depth	TNZ T/3	I	0.6 mm minimum
	Chip take	Chip retention	Visual	C & I	95% minimum on trafficked areas (wheel interface) 90% minimum on untrafficked areas
	Site safety	—	—		See contract conditions
	Colour uniformity	Colour change	BS 1006/A02	C	Maximum difference from surrounding pavement
	Roadmarking contrast	Texture	TNZ T/3	1	0.6 mm minimum
Environmental	Noise	Texture depth	TNZ T/3	1	As specified in Schedule A
Waterproofness	Impermeable	Chip size	NZS 4407, Test 3.13	C	For single coat seals ALD = 5.5 mm minimum For multilayer seals the larger chip ALD =5.5 mm minimum For texturising seals and void fills N/A
Economics	Tyre wear	Aggregate PSV Texture depth	TNZ M/6 TNZ T/3	C I	N/A N/A
	Rolling resistance	Texture depth	TNZ T/3	I	N/A
Durability	Aggregate	Crushing value Weathering resistance			
	Bitumen	Durability Flux content		C C	Bitumen complies to TNZ M/1 As specified in Schedule A
	Bitumen application rate	Texture depth	TNZ T/3	I	Minimum texture depth as specified in Clauses 13.2.1, 13.2.2, 13.2.3 and 13.2.4.

* C = at time of construction, I = 10-12 months after construction

** where doubt exists this criterion shall be measured at time of construction

9. COMPLIANCE ASSESSMENT

9.1 Assessment Period and Test Sections

For single and multilayer seals the Engineer shall test for compliance with surface texture and chip retention between 10 to 12 months after construction of the chipseal.

For texturising and void fills the timing of the final assessment will be defined in the Schedule to this contract.

For assessment of single coat seals, multilayer seals, texturising seals and void fills the pavement will be divided into sections of up to 200 m length.

9.2 Surface Texture

9.2.1 Requirements for Single Coat and Multilayer Seals

Through the use of a random sampling scheme, a longitudinal location shall be selected within each section and surface texture measurements taken either across the width between the pavement edge lines or where edge lines are not present the total sealed width shall be assessed. The measurements shall be taken at the following locations as defined in TNZ T/4 Specification:

Outer wheel path, between wheel path, centreline, inner wheel path, outer wheel path. Where the site consists of more than one section the inner wheel path and between wheel path measurements shall be performed alternating from one lane to the other for each section.

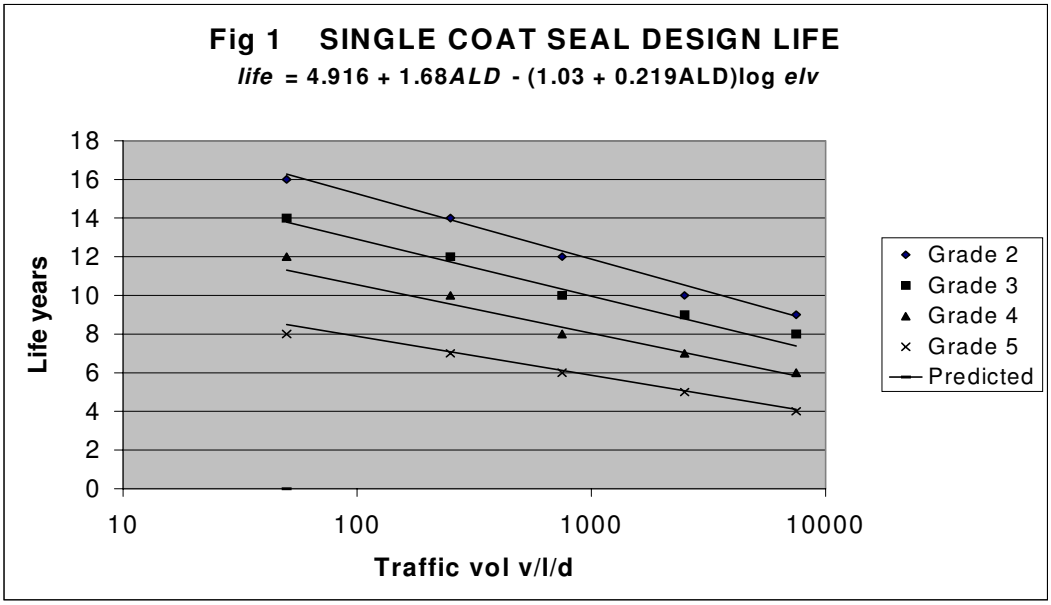
The surface texture will be accepted if the texture depth is greater than that required to obtain the design life of the seal.

Unless noted in the schedule for the site the design life in years is defined as:

For single coat seals

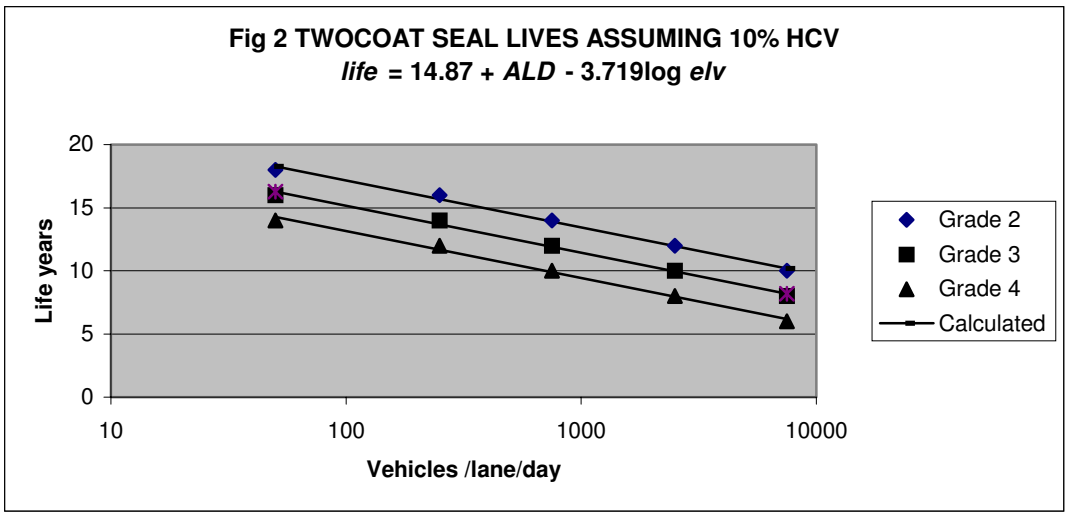
(1)

$$Yd = 4.916 + 1.68\ ALD - (1.03 + 0.219\,ALD)\log elv$$



For multilayer seals:

$$Yd = 14.87 + ALD - 3.719 \log elv \qquad (2)$$



where: Yd = design life in years

elv = equivalent light vehicles/lane/day.

ALD = average least dimension of the sealing chip in mm used on the section. For multilayer seals the larger ALD is used.

Equivalent light vehicles/lane/day is calculated as:

$$elv = \frac{AADT}{No\ of\ lanes}\left(1 + \frac{9(HCV)}{100}\right) \qquad (3)$$

where AADT = annual average daily traffic on the road section.

HCV = percentage heavy commercial vehicles.

The minimum value of the average texture depth calculated from the sand circle test as defined in TNZ T/3 Specification shall be:

$X - 0.519S \geq 0.9 + 0.07$ ALD (log Yd) (4)

where S = sample standard deviation calculated from the 5 tests.

X = average of the texture depth measurements in mm.

9.2.2 Requirements for Texturising Seals

Through the use of a random sampling scheme, a longitudinal location shall be selected within each section and surface texture measurements taken either across the width between the pavement edge lines or where edge lines are not present the total sealed width shall be assessed. The measurements shall be taken at the following locations as defined in TNZ T/4 Specification:

Outer wheel path, between wheel path, centreline, inner wheel path, outer wheel path. Where the site consists of more than one section the inner wheel path and between wheel path measurements shall be performed alternating from one lane to the other for each section.

The surface texture of the section will be accepted if the variability in the texture depth of the surface is within the tolerances specified below:

Td(coarse) - Td(ave) shall be < Min ALD/16.8, and

Td(ave) - Td(fine) shall be < Min ALD/16.8

Where:

Td (coarse) = the maximum texture depth in mm

Td (ave) = the average texture depth in mm

Td (fine) = the minimum texture depth in mm

Min ALD = the minimum average least dimension in mm of the proposed reseal chip to follow the texturising seal as detailed in the schedule.

Sections that do not comply with the texture depth requirements will be accepted only if the Contractor can demonstrate through quality records that the residual binder application rate used was between 0.55 l/m^2 and 0.85 l/m^2 for a Grade 6 chip and 0.75 l/m^2 and 1.1 l/m^2 for a Grade 5 chip. If the binder application rates traditionally used in the contract location differ from these application rates, then approval must be obtained from the Engineer to modify these rates to reflect local practice.

9.2.3 Void Fills

Through the use of a random sampling scheme, a longitudinal location shall be selected within each section and surface texture measurements taken either across the width between the pavement edge lines or where edge lines are not present the total sealed width shall be assessed. The measurements shall be taken at the following locations as defined in TNZ T/4 Specification:

Outer wheel path, between wheel path, centreline, inner wheel path, outer wheel path. Where the site consists of more than one section the inner wheel path and between wheel path measurements shall be performed alternating from one lane to the other for each section.

The surface shall have a uniform texture with an average texture depth of greater than 1.0mm and no test with less than 0.75 mm.

9.3 Chip Retention

For single coat seals, multilayer seals and void fills, a visual assessment of the surface shall be performed to assess the level of chip coverage and retention. Chip retention shall be assessed by determining the chip coverage on any 300 mm x 300 mm area.

The section shall be rejected if any 3 locations assessed have less than 95% chip coverage on any trafficked area (wheel interface) or 90% on untrafficked areas (e.g. untrafficked centrelines, shoulder areas).

All areas of chip loss greater than above must be repaired within the timeframes specified in the contract document.

For texturising seals there are no requirements for chip retention.

9.4 Retesting

Where either the Contractor or Engineer considers that the section acceptance or compliance testing for texture does not reflect the true condition of the seal then either party may elect to retest the section using the TRL Mini Texture meter or other agreed method. The mini texture meter shall be operated in accordance with the manufacturer's instructions at a speed of 3 km/h ±0.5 km/h.

The texture depth measured with the mini texture meter shall be converted to the equivalent texture depth derived from the sand circle test using the following equation:

$$\mathbf{TD = 1.64MTM - 0.13} \qquad \mathbf{(5)}$$

Where TD is the sand circle derived texture depth
MTM is the average texture depth from the mini texture meter.

The average texture for each wheelpath shall be measured for the full length of the section. The decision to either accept the section or apply proportional payment shall be based on consideration of each section. The wheeltrack with the lowest average texture depth will be used to assess compliance.

The section will be accepted if the mean texture depth of the wheelpath is greater than the value calculated from equation (4), where S (the standard deviation) is taken as zero.

10. MAINTENANCE

It is the Contractor's responsibility to maintain the seal in accordance with the requirements of this specification in a safe condition from the construction date until the final acceptance by the Engineer.

10.1 Repairs

For seals that have chips that are in the range of grade 2 to 4 any repairs shall be performed using a chip with an ALD within 0.5 mm of the original chip used for construction.

For seals that are using chip sizes grade 5 or 6 then the repair must be performed with the same grade as the original chip. The chip used for repairs shall also be from the same source as the original construction.

If at any time during the maintenance period repairs are required over an area greater than 10% of the area of the section then the proposed repair technique and acceptance criteria shall be agreed with the Engineer.

Any areas repaired more than nine months after construction will, at the discretion of the Engineer, be subjected to a further 12 months maintenance period. If the area of repairs at the end of 12 months are greater than 10% of

the section and revised acceptance criteria has not been agreed with the Engineer, then the section will be subject to a further 12 month maintenance period.

For texturising seals and void fills the maintenance period is defined in the schedule.

10.2 Contractors Response Time for Intervening

If at any time during the maintenance period intervention by the Contractor is required due to loose or lost chip or loss of skid resistance or surface texture below the values in Table 1, in accordance with SOMAC clause 10.2 (Resealing) the Contractor shall:

- respond within 48 hours with positive action to mitigate and control the risk to the road users (signs and sweeping alone may not be considered as appropriate positive action in every event).

- undertake corrective repairs when conditions permit the most appropriate repair to be successfully completed. These repairs must ensure the expected design life of the seal is not compromised. If necessary these corrective repairs may be undertaken later in the maintenance period.

11. PAYMENT

Payment will be made between two and four weeks after construction subject to:

- The Contractor supplying texture depth test results used for the design for single coat and multilayer seals.

- Evidence of compliance with this specification.

11.1 Single Coat Seals

Payment will be made in accordance with the tendered square metre rate for completed seal in the schedule of prices, plus additional payment for residual binder based on the surface texture depth of the existing pavement. The quantity of binder for which additional payment will be made shall be determined from:

$$\textbf{Binder rate (l/m}^2\textbf{)} = \textbf{(0.21 Td - 0.05) x Tf} \qquad \textbf{(6)}$$

where Td = average texture depth in mm of the pavement before resealing as determined by TNZ T/3 Specification

$Td = 57{,}300/d^2$

d = sandcircle diameter as determined by TNZ T/3

Tf = traffic factor given in the Bituminous Sealing Manual.

If after the 12 month assessment the texture depth is below the specified minimum, payment for the section shall be reduced as follows:

- For areas where $\frac{Yf}{Yd} \geq 0.75$ equation (7) shall be used to calculate the reduction in payment.

$$PR = 100\left(1 - \frac{1.1^{Yf} - 1}{1.1^{Yd} - 1} \times 1.1^{Yd-Yf}\right) \qquad \textbf{(7)}$$

where PR = percentage payment reduction

Yd = design life as calculated from equation (1) in Clause 13.2.1 of this specification.

Y_f = expected life before flushing, calculated as follows

Note: The discount rate is 10% therefore a factor of 1.1 is used in formula (7).

$$Yf = anti\log\left[\frac{TD - 0.9}{0.07 ALD}\right] \qquad \textbf{(8)}$$

where elv = equivalent light vehicles/lane/day from equation (3)

ALD = average least dimension of the sealing chip in mm used on the section.

TD = the average texture depth for the section X - 0.519S as defined in Clause 13.2.1 of this specification.

- For areas where $\frac{Yf}{Yd} < 0.75$ but ≥ 0.4 equation (9) shall be used to

$$PR = \frac{L - 25}{35}(100 - PR_{25}) + PR_{25} \qquad \textbf{(9)}$$

calculate the reduction in payment.

where: L = percentage loss of the design life $100\left(1 - \frac{Yf}{Yd}\right)$

PR_{25} = payment reduction calculated from equation (7) for a 25% reduction in design life.

- For areas where $\frac{Yf}{Yd} < 0.4$ no payment shall be made.

11.2 Multilayer Seals

Payment will be made in accordance with the tendered square metre rates plus additional payment for residual binder based on the surface texture depth of the existing pavement and calculated as specified in Clause 11.1 above.

If after the 12 month assessment the texture depth is below the specified minimum, payment for the section shall be reduced as specified in Clause 11.1 above.

11.3 Texturising Seals and Void Fills

Payment will be made in accordance with the tendered square metre rate for sections complying with this specification.

Payment will not be made for sections that do not comply with the requirements of this specification.

However for texturising seals if the Contractor can demonstrate through quality records that the binder application rate used was in accordance with the tolerances specified in clause 9.2.2 of this specification, then full payment will be made.

RESEALS AND SECOND COAT SEALING
CONTRACT:

SCHEDULE A

SINGLE AND MULTILAYER SEALS

Road	RP Start	RP Finish	Width (m)	Area (m^2)	AADT (note 2)	% HCV	Design Life (note 1)	Existing Surface	Last Year Sealed	Chip PSV Minimum	1st Chip ALD Minimum	2nd Chip Grade	Bitumen Grade	Flux Content pph of Bitumen	Reason for Sealing

Note 1: Only if different from that given in equation (1) of Clause 13.2.1 of this specification.
Note2: A distinction is made in the AADT column between reliable estimates based on known data (C) and less accurate data (E).

VOID FILLS AND TEXTURISING

Road	RP Start	RP Finish	Width (m)	Area (m^2)	AADT (note 2)	% HCV	Proposed reseal chip ALD min (note 1)	Existing Surface	Last Year Sealed	Chip PSV Minimum	Chip Grade	Bitumen Grade	Flux Content pph of Bitumen	Maintenance Period	Reason for Sealing

Note 1: Only for texturising seals.
Note2: A distinction is made in the AADT column between reliable estimates based on known data (C) and less accurate data (E).

Appendix C ARMIS layer data sample

Data for Road Section : 21A - PALMERSTON HIGHWAY (INNISFAIL-RAVENSHOE)

District ID	TDIST_START	TDIST_END	Layer Number	Layer type	Layer Category	Job Number	Layer Depth	Layer Date	Depth from surface	Base Layer Number	Layer Category Name	Layer Type Name	No Element Selected	Carriageway Code	Lane Code	AADT	%HV	Lane count
11	0	0.05	1	G3	G	66/21A/807	35	39892	0	---	Dense Graded Asphalt	Stone Mastic Asphalt	11	1	1	2201	23.56	2
11	0	0.05	2	K2	K	66/21A/807	10	39892	35	---	Spray Seal	PMB Spray Seal	11	1	1	2201	23.56	2
11	0	0.05	3	K1	K	66/21A/716	7	34614	45	---	Spray Seal	Bitumen Spray Seal	11	1	1	2201	23.56	2
11	0	0.05	4	K1	K	378	20	32731	52	---	Spray Seal	Bitumen Spray Seal	11	1	1	2201	23.56	2
11	0	0.05	5	B1	B	378	300	29819	72	1	Granular	Standard Granular	11	1	1	2201	23.56	2
11	0	0.05	6	A1	A	378	1	29819	372	---	Subgrade	Natural Soil Subgrade	11	1	1	2201	23.56	2
11	0.05	0.07	1	K1	K	66/21A/716	7	34614	0	---	Spray Seal	Bitumen Spray Seal	11	1	1	2201	23.56	2
11	0.05	0.07	2	K1	K	378	20	32731	7	---	Spray Seal	Bitumen Spray Seal	11	1	1	2201	23.56	2
11	0.05	0.07	3	B1	B	378	300	29819	27	1	Granular	Standard Granular	11	1	1	2201	23.56	2
11	0.05	0.07	4	A1	A	378	1	29819	327	---	Subgrade	Natural Soil Subgrade	11	1	1	2201	23.56	2
11	0.07	0.4	1	K2	K	66/21A/726	7	38383	0	---	Spray Seal	PMB Spray Seal	11	1	1	2201	23.56	2
11	0.07	0.4	2	K1	K	66/21A/716	7	34614	7	---	Spray Seal	Bitumen Spray Seal	11	1	1	2201	23.56	2
11	0.07	0.4	3	K1	K	378	20	32731	14	---	Spray Seal	Bitumen Spray Seal	11	1	1	2201	23.56	2
11	0.07	0.4	4	B1	B	378	300	29819	34	1	Granular	Standard Granular	11	1	1	2201	23.56	2
11	0.07	0.4	5	A1	A	378	1	29819	334	---	Subgrade	Natural Soil Subgrade	11	1	1	2201	23.56	2
11	0.4	0.5	1	K2	K	66/21A/726	7	38383	0	---	Spray Seal	PMB Spray Seal	11	1	1	2201	23.56	2
11	0.4	0.5	2	K1	K	66/21A/716	7	34614	7	---	Spray Seal	Bitumen Spray Seal	11	1	1	2201	23.56	2

Appendix D ARMIS yearly texture depth data sample

21A - PALMERSTON HIGHWAY (INNISFAIL-RAVENSHOE)

TDIST_START	TDIST_END	22/09/2006 2007 Sensor Measured Texture Depth OWP	2007 Standard Deviation OWP	2007 Sensor Measured Texture Depth BWP	2007 Standard Deviation BWP	30/06/2005 2006 Sensor Measured Texture Depth OWP	2006 Standard Deviation OWP	2006 Sensor Measured Texture Depth BWP	2006 Standard Deviation BWP	2005 Sensor Measured Texture Depth OWP	2005 Standard Deviation OWP	2005 Sensor Measured Texture Depth BWP	2005 Standard Deviation BWP	13/07/2004 2004 Sensor Measured Texture Depth OWP	2004 Standard Deviation OWP	2004 Sensor Measured Texture Depth BWP	2004 Standard Deviation BWP	7/04/2003 2003 Sensor Measured Texture Depth OWP	2003 Standard Deviation OWP
0	0.1					0.56	0.46	0.64	0.53	0.45	0.14	0.36	0.15	0.51	0.43	0.57	0.42	0.51	0.39
0.1	0.2					0.31	0.09	0.38	0.06	0.54	0.17	0.34	0.09	0.26	0.08	0.36	0.1	0.23	0.08
0.2	0.3					0.39	0.1	0.49	0.11	0.57	0.12	0.51	0.14	0.42	0.15	0.51	0.21	0.41	0.15
0.3	0.4					0.31	0.08	0.37	0.08	0.57	0.12	0.4	0.09	0.3	0.14	0.31	0.09	0.27	0.08
0.4	0.5					0.33	0.08	0.49	0.09	0.48	0.1	0.45	0.08	0.32	0.07	0.5	0.12	0.25	0.06
0.5	0.6					0.34	0.07	0.54	0.11	0.59	0.1	0.5	0.1	0.33	0.1	0.67	0.26	0.34	0.11
0.6	0.7					0.36	0.07	0.51	0.1	0.54	0.08	0.5	0.1	0.31	0.09	0.6	0.19	0.28	0.09
0.7	0.8					0.33	0.09	0.56	0.1	0.55	0.1	0.57	0.11	0.31	0.08	0.57	0.17	0.29	0.08
0.8	0.9					0.36	0.09	0.55	0.12	0.61	0.1	0.55	0.11	0.38	0.12	0.5	0.13	0.37	0.1
0.9	1					0.29	0.07	0.49	0.09	0.56	0.12	0.51	0.11	0.29	0.1	0.47	0.12	0.3	0.1
1	1.1					0.38	0.09	0.57	0.11	0.53	0.11	0.57	0.1	0.4	0.12	0.52	0.1	0.36	0.1
1.1	1.2					0.39	0.08	0.59	0.11	0.64	0.11	0.6	0.11	0.5	0.18	0.63	0.14	0.44	0.12
1.2	1.3					0.34	0.07	0.52	0.11	0.58	0.12	0.59	0.12	0.34	0.09	0.58	0.15	0.29	0.07
1.3	1.4					0.35	0.09	0.54	0.12	0.6	0.11	0.51	0.11	0.36	0.1	0.48	0.17	0.43	0.13
1.4	1.5					0.34	0.08	0.57	0.11	0.6	0.11	0.5	0.13	0.35	0.13	0.75	0.23	0.36	0.15
1.5	1.6					0.32	0.08	0.49	0.09	0.56	0.09	0.51	0.1	0.28	0.08	0.55	0.15	0.27	0.08
1.6	1.7					0.34	0.08	0.54	0.11	0.54	0.1	0.5	0.1	0.38	0.13	0.51	0.13	0.38	0.14
1.7	1.8					0.33	0.09	0.46	0.1	0.63	0.11	0.45	0.1	0.39	0.12	0.52	0.15	0.37	0.14
1.8	1.9					0.27	0.06	0.48	0.09	0.56	0.1	0.44	0.1	0.27	0.05	0.45	0.12	0.27	0.07
1.9	2					0.31	0.08	0.49	0.1	0.49	0.08	0.48	0.11	0.29	0.08	0.52	0.15	0.26	0.07
2	2.1					0.32	0.09	0.52	0.14	0.49	0.08	0.53	0.12	0.29	0.09	0.59	0.22	0.32	0.13
2.1	2.2					0.34	0.07	0.5	0.11	0.53	0.12	0.54	0.13	0.32	0.11	0.67	0.16	0.3	0.1
2.2	2.3					0.36	0.08	0.53	0.11	0.51	0.08	0.59	0.12	0.29	0.07	0.62	0.18	0.3	0.07
2.3	2.4					0.5	0.11	0.63	0.11	0.59	0.12	0.61	0.13	0.52	0.14	0.78	0.18	0.51	0.14
2.4	2.5					0.48	0.12	0.58	0.12	0.66	0.1	0.61	0.12	0.46	0.15	0.63	0.2	0.45	0.13
2.5	2.6					0.3	0.09	0.4	0.1	0.52	0.12	0.44	0.11	0.3	0.13	0.41	0.17	0.28	0.11
2.6	2.7					0.34	0.09	0.46	0.11	0.56	0.11	0.48	0.1	0.38	0.16	0.5	0.17	0.37	0.14
2.7	2.8					0.31	0.06	0.48	0.1	0.49	0.08	0.5	0.11	0.34	0.12	0.62	0.16	0.31	0.11
2.8	2.9					0.32	0.07	0.55	0.12	0.54	0.09	0.52	0.11	0.38	0.12	0.6	0.16	0.32	0.08
2.9	3					0.31	0.07	0.47	0.11	0.52	0.11	0.52	0.11	0.33	0.11	0.54	0.17	0.38	0.11
3	3.1					0.28	0.06	0.52	0.11	0.54	0.08	0.44	0.09	0.25	0.06	0.59	0.21	0.3	0.09
3.1	3.2					0.36	0.07	0.55	0.1	0.5	0.08	0.52	0.11	0.34	0.09	0.53	0.14	0.34	0.13
3.2	3.3					0.37	0.07	0.52	0.1	0.58	0.1	0.48	0.1	0.48	0.17	0.72	0.2	0.46	0.18
3.3	3.4					0.31	0.08	0.42	0.11	0.61	0.1	0.49	0.09	0.43	0.18	0.6	0.21	0.46	0.16
3.4	3.5					0.35	0.33	0.49	0.24	0.48	0.08	0.42	0.11	0.4	0.19	0.66	0.22	0.4	0.14
3.5	3.6					0.42	0.12	0.56	0.16	0.57	0.11	0.57	0.13	0.63	0.31	0.86	0.35	0.53	0.18
3.6	3.7					0.43	0.08	0.46	0.11	0.62	0.14	0.62	0.18	0.43	0.18	0.66	0.2	0.47	0.22
3.7	3.8					0.46	0.1	0.52	0.11	0.62	0.12	0.55	0.12	0.65	0.17	0.71	0.15	0.58	0.18
3.8	3.9					0.49	0.12	0.57	0.19	0.74	0.17	0.62	0.15	0.76	0.27	0.87	0.27	0.62	0.26
3.9	4					0.33	0.09	0.55	0.15	0.61	0.22	0.59	0.12	0.33	0.17	0.7	0.18	0.25	0.08

Appendix E Matlab program script

```
%sealage.m
%by Andrew Armstrong
%import layer data set (SealAgeData)
%find all sprayed seals and calculate the age of each
%output seal age data to excel file (sealage)
%output seal position data to excel file (sealpos)


clear;
clc;
%output array counter
count=0;
m=1;
seal='Bitumen Spray Seal';
[r1 r1t] = xlsread('SealAgeData','10n');
[r2 r2t]= xlsread('SealAgeData','10p');
[r3 r3t]= xlsread('SealAgeData','20a');
[r4 r4t]= xlsread('SealAgeData','21a');
[r5 r5t]= xlsread('SealAgeData','32a');
[r6 r6t]= xlsread('SealAgeData','32b');
[r7 r7t]= xlsread('SealAgeData','92b');

%collate seal data for 10n
%work from the bottom of the array
for n=[length(r1):-1:2]
    %change name of array to 'X'
    X=r1;
    %read layer type name from text array (note r1t is 2 rows
longer than r1)
    sealcheck=char(r1t(n+2,13));
    %check if row is 'bitumen spray seal'
    if strncmp(seal, sealcheck, length(seal))==1
        %add 1 to counter
        count=count+1;
        %check for same section of road (if not the same,
skip)
        if X(n,2)~=X(n-1,2)
        %check for the same time of completion (if the same,
skip)
        elseif X(n,9)~=X(n-1,9)
            %check sequence of layers (if not consecutive
numbers, skip)
            if X(n,4)-1==X(n-1,4)
                age=round(((X(n-1,9)-X(n,9))/365)*100)/100;
                %aadt when seal was constructed assuming
growth of 2.5% per
                %year( based on 2007 data)
                aadt=round(X(n,17)*0.975^(age-2));
                vld=round(aadt/X(n,19));
                sage(m,:)=[age X(n,8) aadt vld X(n,18)];
                %create spos array [road number, start
chainage, end
                %chainage, construction year, seal size]
                spos(m,:)=[1 X(n,2) X(n,3) X(n,9) X(n,8)];
                %increase array counter
                m=m+1;
            end
        end
    end
end
%collate seal data for 10p
```

```
for n=[length(r2):-1:2]
    X=r2;
    sealcheck=char(r2t(n+2,13));
    if strncmp(seal, sealcheck, length(seal))==1
        count=count+1;
        %check for same section of road (if not the same,
skip)
        if X(n,2)~=X(n-1,2)
        %check for the same time of completion (if the same,
skip)
        elseif X(n,9)~=X(n-1,9)
            %check sequence of layers (if not consecutive
numbers, skip)
            if X(n,4)-1==X(n-1,4)
                age=round(((X(n-1,9)-X(n,9))/365)*100)/100;
                %aadt when seal was constructed assuming
growth of 2.5% per
                %year( based on 2007 data)
                aadt=round(X(n,17)*0.975^(age-2));
                vld=round(aadt/X(n,19));
                sage(m,:)=[age X(n,8) aadt vld X(n,18)];
                spos(m,:)=[2 X(n,2) X(n,3) X(n,9) X(n,8)];
                m=m+1;
            end
        end
    end
end
%collate seal data for 20a
for n=[length(r3):-1:2]
    X=r3;
    sealcheck=char(r3t(n+2,13));
    if strncmp(seal, sealcheck, length(seal))==1
        count=count+1;
        %check for same section of road (if not the same,
skip)
        if X(n,2)~=X(n-1,2)
        %check for the same time of completion (if the same,
skip)
        elseif X(n,9)~=X(n-1,9)
            %check sequence of layers (if not consecutive
numbers, skip)
            if X(n,4)-1==X(n-1,4)
                age=round(((X(n-1,9)-X(n,9))/365)*100)/100;
                %aadt when seal was constructed assuming
growth of 2.5% per
                %year( based on 2007 data)
                aadt=round(X(n,17)*0.975^(age-2));
                vld=round(aadt/X(n,19));
                sage(m,:)=[age X(n,8) aadt vld X(n,18)];
                spos(m,:)=[3 X(n,2) X(n,3) X(n,9) X(n,8)];
                m=m+1;
            end
        end
    end
end
%collate seal data for 21a
for n=[length(r4):-1:2]
    X=r4;
    sealcheck=char(r4t(n+2,13));
    if strncmp(seal, sealcheck, length(seal))==1
        count=count+1;
```

```
        %check for same section of road (if not the same,
skip)
        if X(n,2)~=X(n-1,2)
        %check for the same time of completion (if the same,
skip)
        elseif X(n,9)~=X(n-1,9)
            %check sequence of layers (if not consecutive
numbers, skip)
            if X(n,4)-1==X(n-1,4)
                age=round(((X(n-1,9)-X(n,9))/365)*100)/100;
                %aadt when seal was constructed assuming
growth of 2.5% per
                %year( based on 2007 data)
                aadt=round(X(n,17)*0.975^(age-2));
                vld=round(aadt/X(n,19));
                sage(m,:)=[age X(n,8) aadt vld X(n,18)];
                spos(m,:)=[4 X(n,2) X(n,3) X(n,9) X(n,8)];
                m=m+1;
            end
        end
    end
end
%collate seal data for 32a
for n=[length(r5):-1:2]
    X=r5;
    sealcheck=char(r5t(n+2,13));
    if strncmp(seal, sealcheck, length(seal))==1
        count=count+1;
        %check for same section of road (if not the same,
skip)
        if X(n,2)~=X(n-1,2)
        %check for the same time of completion (if the same,
skip)
        elseif X(n,9)~=X(n-1,9)
            %check sequence of layers (if not consecutive
numbers, skip)
            if X(n,4)-1==X(n-1,4)
                age=round(((X(n-1,9)-X(n,9))/365)*100)/100;
                %aadt when seal was constructed assuming
growth of 2.5% per
                %year( based on 2007 data)
                aadt=round(X(n,17)*0.975^(age-2));
                vld=round(aadt/X(n,19));
                sage(m,:)=[age X(n,8) aadt vld X(n,18)];
                spos(m,:)=[5 X(n,2) X(n,3) X(n,9) X(n,8)];
                m=m+1;
            end
        end
    end
end
%collate seal data for 32b
for n=[length(r6):-1:2]
    X=r6;
    sealcheck=char(r6t(n+2,13));
    if strncmp(seal, sealcheck, length(seal))==1
        count=count+1;
        %check for same section of road (if not the same,
skip)
        if X(n,2)~=X(n-1,2)
        %check for the same time of completion (if the same,
skip)
```

```
        elseif X(n,9)~=X(n-1,9)
            %check sequence of layers (if not consecutive
numbers, skip)
            if X(n,4)-1==X(n-1,4)
                age=round(((X(n-1,9)-X(n,9))/365)*100)/100;
                %aadt when seal was constructed assuming
growth of 2.5% per
                %year( based on 2007 data)
                aadt=round(X(n,17)*0.975^(age-2));
                vld=round(aadt/X(n,19));
                sage(m,:)=[age X(n,8) aadt vld X(n,18)];
                spos(m,:)=[6 X(n,2) X(n,3) X(n,9) X(n,8)];
                m=m+1;
            end
        end
    end
end
%collate seal data for 92b
for n=[length(r7):-1:2]
    X=r7;
    sealcheck=char(r7t(n+2,13));
    if strncmp(seal, sealcheck, length(seal))==1
        count=count+1;
        %check for same section of road (if not the same,
skip)
        if X(n,2)~=X(n-1,2)
        %check for the same time of completion (if the same,
skip)
        elseif X(n,9)~=X(n-1,9)
            %check sequence of layers (if not consecutive
numbers, skip)
            if X(n,4)-1==X(n-1,4)
                age=round(((X(n-1,9)-X(n,9))/365)*100)/100;
                %aadt when seal was constructed assuming
growth of 2.5% per
                %year( based on 2007 data)
                aadt=round(X(n,17)*0.975^(age-2));
                vld=round(aadt/X(n,19));
                sage(m,:)=[age X(n,8) aadt vld X(n,18)];
                spos(m,:)=[7 X(n,2) X(n,3) X(n,9) X(n,8)];
                m=m+1;
            end
        end
    end
end

%set sealpos array row counter
m=1;
%define sealops matrix
sealpos=[1 1 1 1 1];
%for each data point
for n=[1:1:length(spos)]
    %set construction year
    syear=spos(n,4);
    %set seal size
    ssize=spos(n,5);
    %set road number
    sroad=spos(n,1);
    %find all sections with the same date, size and road
number
    % if section has already been recorded skip data
```

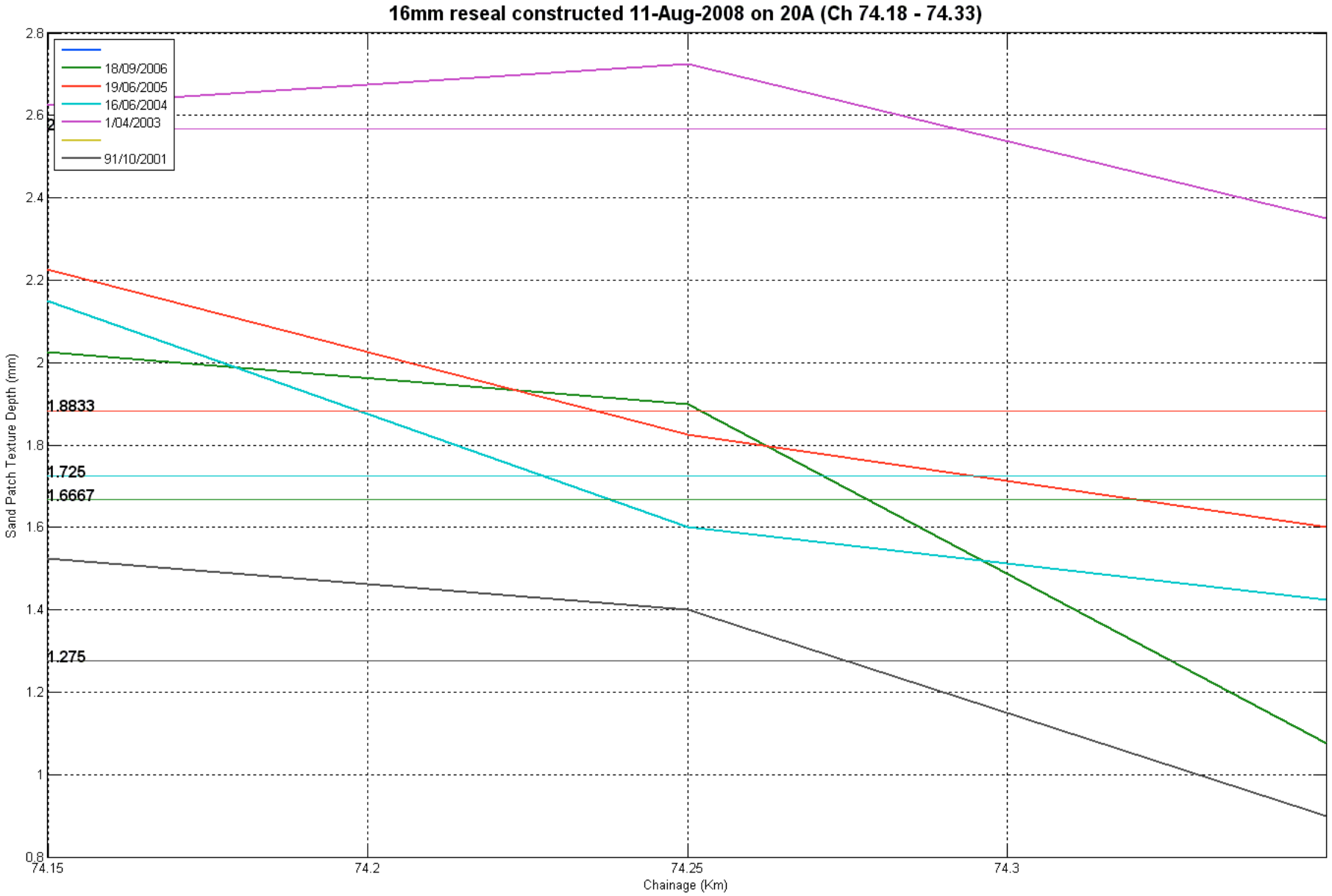
```
    if
find(sealpos(:,3)==syear&sealpos(:,4)==ssize&sealpos(:,5)==sr
oad)
        %test loop
        looptest(n)=1;
    %create sealpos matrix if seal was constructed after
1/1/2000
    elseif syear>36525
        %test loop
        looptest(n)=0;
        %find all data points pertaining to the individual
seal

q=find(spos(:,4)==syear&spos(:,5)==ssize&spos(:,1)==sroad);
        %create array [end chainage, start chainage,
construction year,
        %seal size, road)
        sealpos(m,:)=[spos(q(1),3) spos(q(length(q)),2) syear
ssize sroad];
        %add 1 to sealpos array counter
        m=m+1;
    end
end


xlswrite('SealAge', sage)
xlswrite('SealPos', sealpos)
```

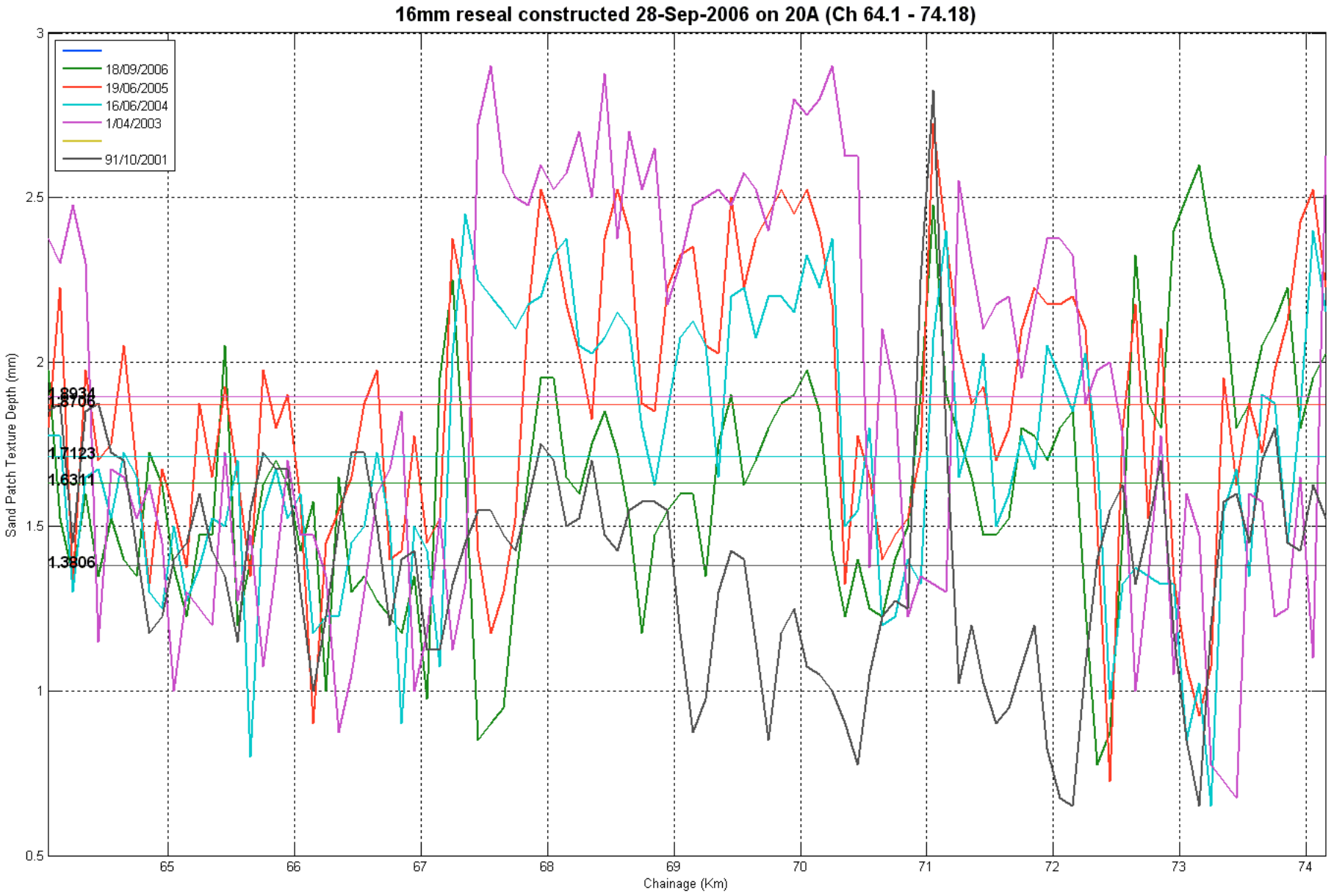
```
%tdreg.m
%By Andrew Armstrong
%Import Sealpos data
%find all texture depth data for the seal
%plot yearly texture depth over the section of road
%plot average yearly texture depth over the section of road
%Output average texture depths to excel file (SealTD)


clear;
clc;
[s1]=xlsread('SealPos');
fulltd=zeros(1,10);
for n=[1:1:length(s1)]
    counter=1;
    road=s1(n,5);
    switch road
        case 1
        [rtd rtt]= xlsread('networkTD','10n','A3:J410');
        rdname='10N';
        case 2
        [rtd rtt]= xlsread('networkTD','10p','A3:J861');
        rdname='10P';
        case 3
        [rtd rtt]= xlsread('networkTD','20a','A3:J758');
        rdname='20A';
        case 4
        [rtd rtt]= xlsread('networkTD','21a','A3:J790');
        rdname='21A';
        case 5
        [rtd rtt]= xlsread('networkTD','32a','A3:J493');
        rdname='32A';
        case 6
        [rtd rtt]= xlsread('networkTD','32b','A3:J825');
        rdname='32B';
        case 7
        [rtd rtt]= xlsread('networkTD','92b','A3:J1478');
        rdname='92B';
    end
    if s1(n,1)<rtd(length(rtd),2)&s1(n,2)>rtd(1,1)
        endch=find(rtd(:,2)>s1(n,1),1,'first');
        startch=find(rtd(:,1)<s1(n,2),1,'last');
        if endch==startch
        else
            deltach=(rtd(endch,1)-rtd(startch,1))/(2*(endch-
startch));
            for m=[startch:1:endch]
                ch(counter)=rtd(m)+deltach;
                td(counter,:)=rtd(m,3:9)*2.5;
                counter=counter+1;
            end
            size(1:length(ch),1)=s1(n,4);
            date(1:length(ch),1)=s1(n,3);
            road(1:length(ch),1)=road;
            fulltd=[fulltd; road size date td];

            for m=[1:1:counter-1]
                tdavg(m,:)=mean(td,1);
            end
```

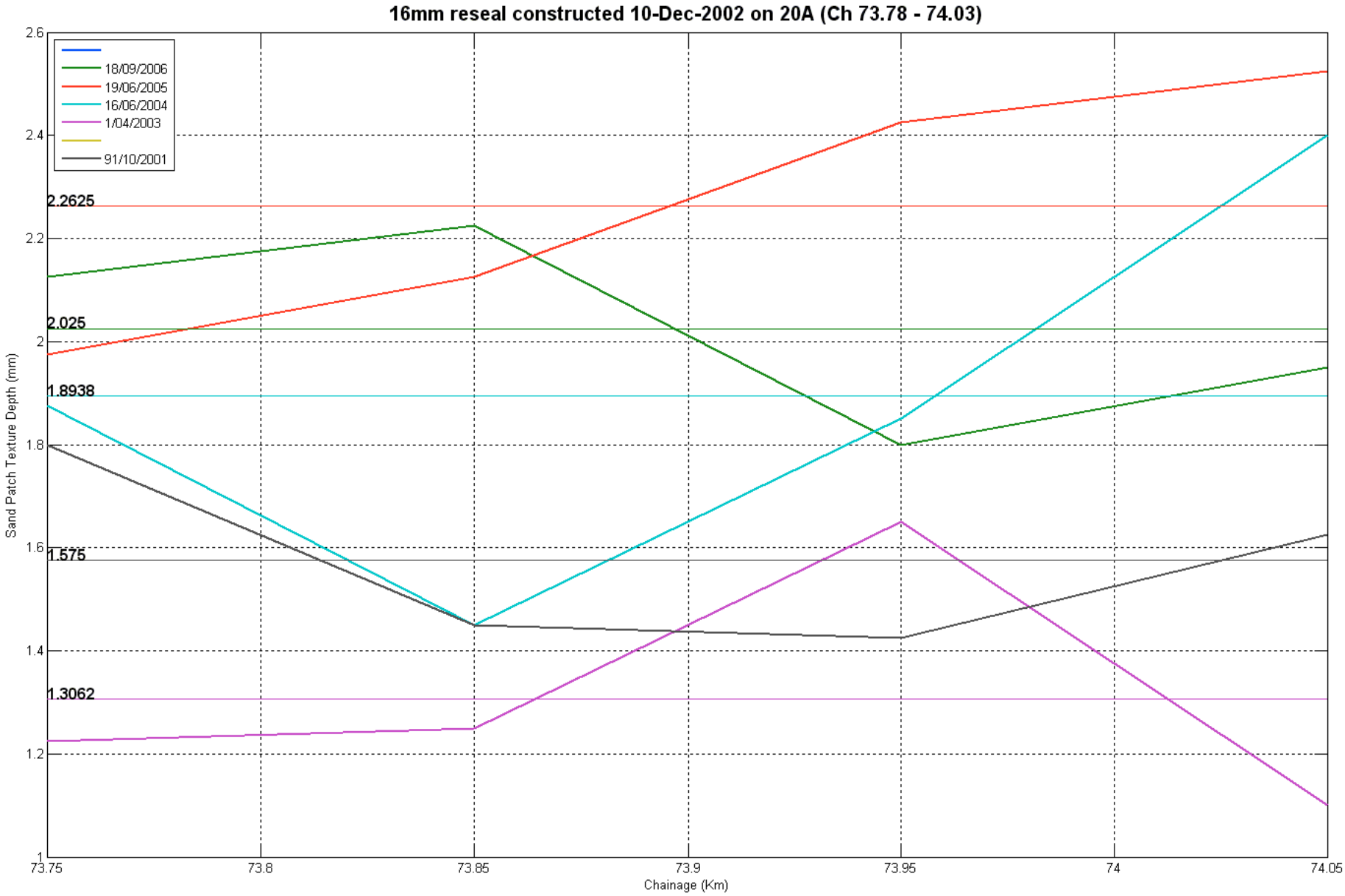
```
            sealdate=datestr(s1(n,3)+693962);
            chstr=[' (Ch ' num2str(s1(n,2)) ' - '
num2str(s1(n,1)) ')'];
            titlestr=[num2str(s1(n,4)) 'mm reseal constructed
' sealdate ' on ' rdname chstr];

            figure('name','Yearly Texture
Depth','menubar','none','Position',...
            get(0,'ScreenSize'));

plot(ch,td(:,1),ch,td(:,2),ch,td(:,3),ch,td(:,4),ch,td(:,5),c
h,td(:,6),ch,td(:,7),'LineWidth',2)

title(titlestr,'fontsize',15,'fontweight','bold');
            xlabel('Chainage (Km)');
            xlim([ch(1) ch(length(ch))]);
            ylabel('Sand Patch Texture Depth (mm)');

legend(char(rtt(3)),char(rtt(4)),char(rtt(5)),char(rtt(6)),ch
ar(rtt(7)),char(rtt(8)),char(rtt(9)),'location','NorthWest');
            grid on;
            hold on

plot(ch,tdavg(:,1),ch,tdavg(:,2),ch,tdavg(:,3),ch,tdavg(:,4),
ch,tdavg(:,5),ch,tdavg(:,6),ch,tdavg(:,7),'LineWidth',0.5)

text(ch(1),tdavg(1,1)+0.01,num2str(tdavg(1,1)),'fontsize',12,
'fontweight','bold')

text(ch(1),tdavg(1,2)+0.01,num2str(tdavg(1,2)),'fontsize',12,
'fontweight','bold')

text(ch(1),tdavg(1,3)+0.01,num2str(tdavg(1,3)),'fontsize',12,
'fontweight','bold')

text(ch(1),tdavg(1,4)+0.01,num2str(tdavg(1,4)),'fontsize',12,
'fontweight','bold')

text(ch(1),tdavg(1,5)+0.01,num2str(tdavg(1,5)),'fontsize',12,
'fontweight','bold')

text(ch(1),tdavg(1,6)+0.01,num2str(tdavg(1,6)),'fontsize',12,
'fontweight','bold')

text(ch(1),tdavg(1,7)+0.01,num2str(tdavg(1,7)),'fontsize',12,
'fontweight','bold')

            file=[rdname '_' num2str(n)];
            saveas(gcf,file,'bmp');

            sealtd(n,:)=[s1(n,:) tdavg(1,:)];


            close
            clear rtd rtt ch td tdavg size date
        end
    else
    end
end
xlswrite('sealTD', sealtd);
```

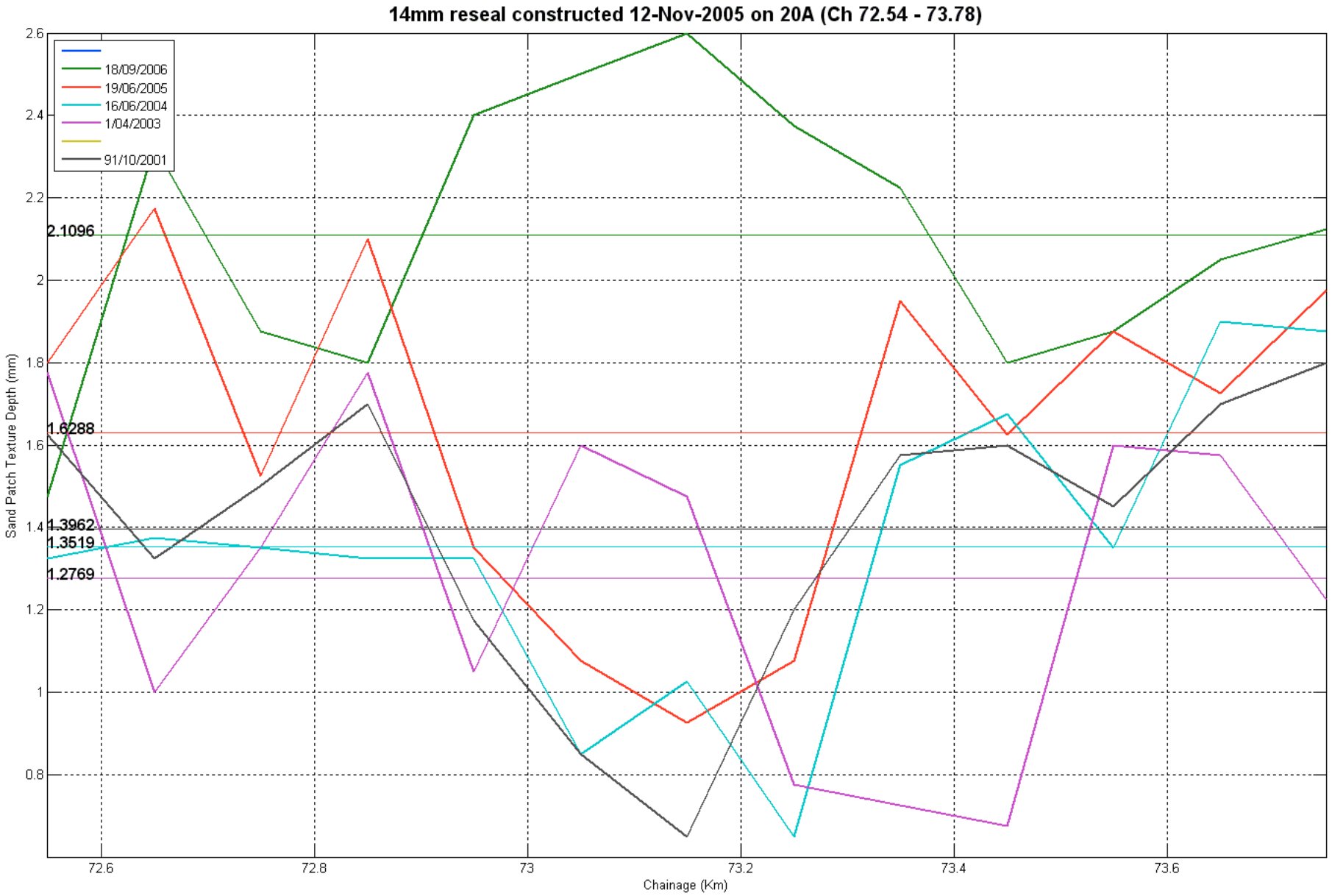
```
%tdrdeg.m
%by Andrew Armstrong
%import average texture depth data from TDdeg
%calculate texture depth predicted by TNZ model for each
section of road
%output texture depth comparison as graphs

[rtd rtt]= xlsread('TDdeg');



for n=[1:1:length(rtd)]
    age=rtd(n,9:15);
    avgtd=rtd(n,16:22);
    tnztd=rtd(n,23:29);
    road=rtd(n,3);

    switch road
        case 1
        rdname='10N';
        case 2
        rdname='10P';
        case 3
        rdname='20A';
        case 4
        rdname='21A';
        case 5
        rdname='32A';
        case 6
        rdname='32B';
        case 7
        rdname='92B';
    end


sealdate=datestr(rtd(n,4)+693960);
chstr=[' (Ch ' num2str(rtd(n,2)) ' - ' num2str(rtd(n,1))
')'];
titlestr=[num2str(rtd(n,5)) 'mm reseal constructed ' sealdate
' on ' rdname chstr];


figure('name','Texture Depth
regression','menubar','none','Position',...
    get(0,'ScreenSize'));
    plot(age,avgtd,'-xb',age,tnztd,'-xr','LineWidth',2)
    title(titlestr,'fontsize',15,'fontweight','bold');
    xlabel('Age of seal (Years)');
    %xlim([ch(1) ch(length(ch))]);
    ylabel('Texture Depth (mm)');
    legend('Average measured Texture Depth','TNZ P17
predicted Texture Depth','location','NorthEast');
    grid on;
    hold on

    file=[ 'deg' rdname '_' num2str(n)];
    saveas(gcf,file,'bmp');

end
```

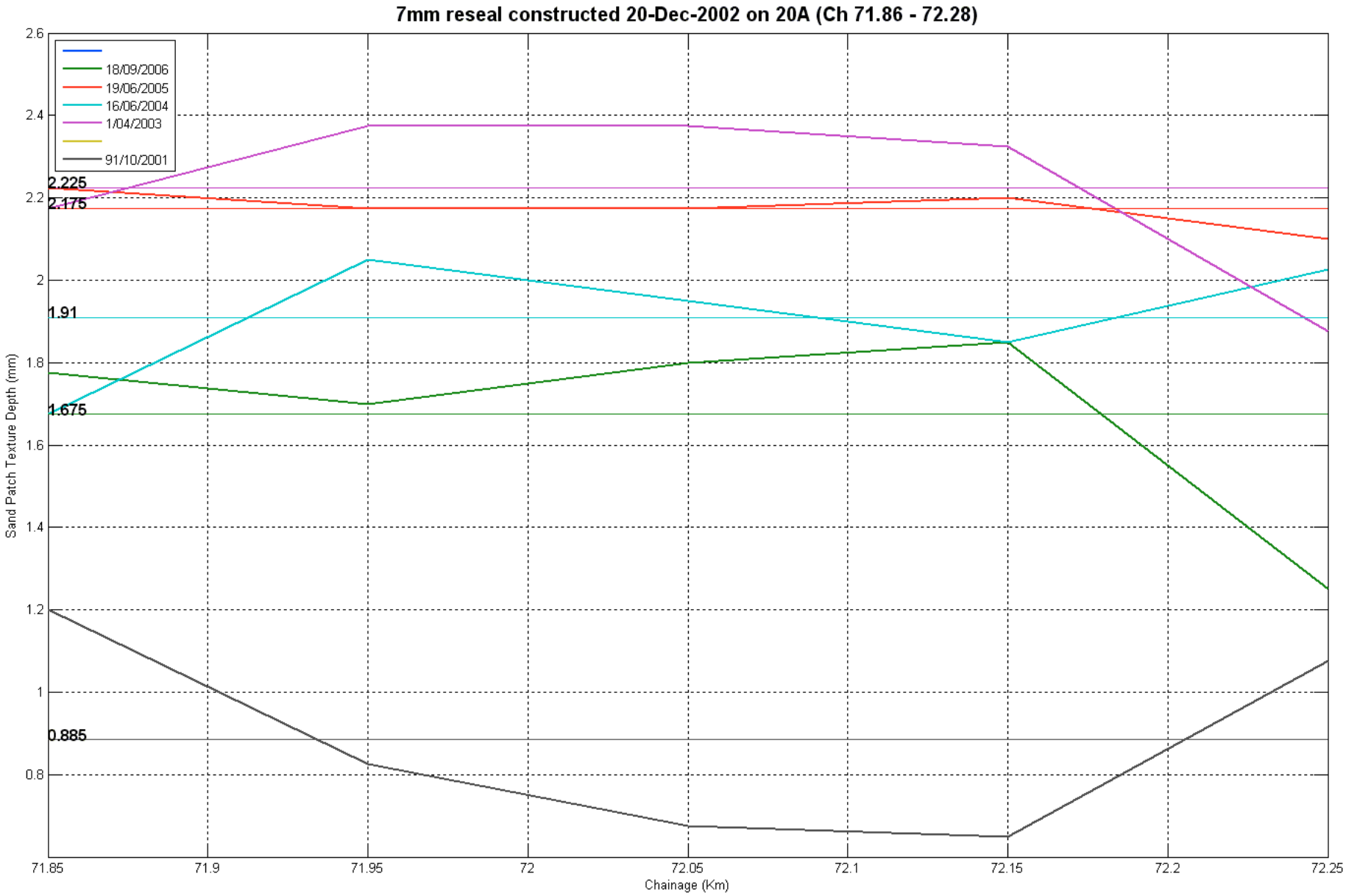
Appendix F yearly texture depth charts

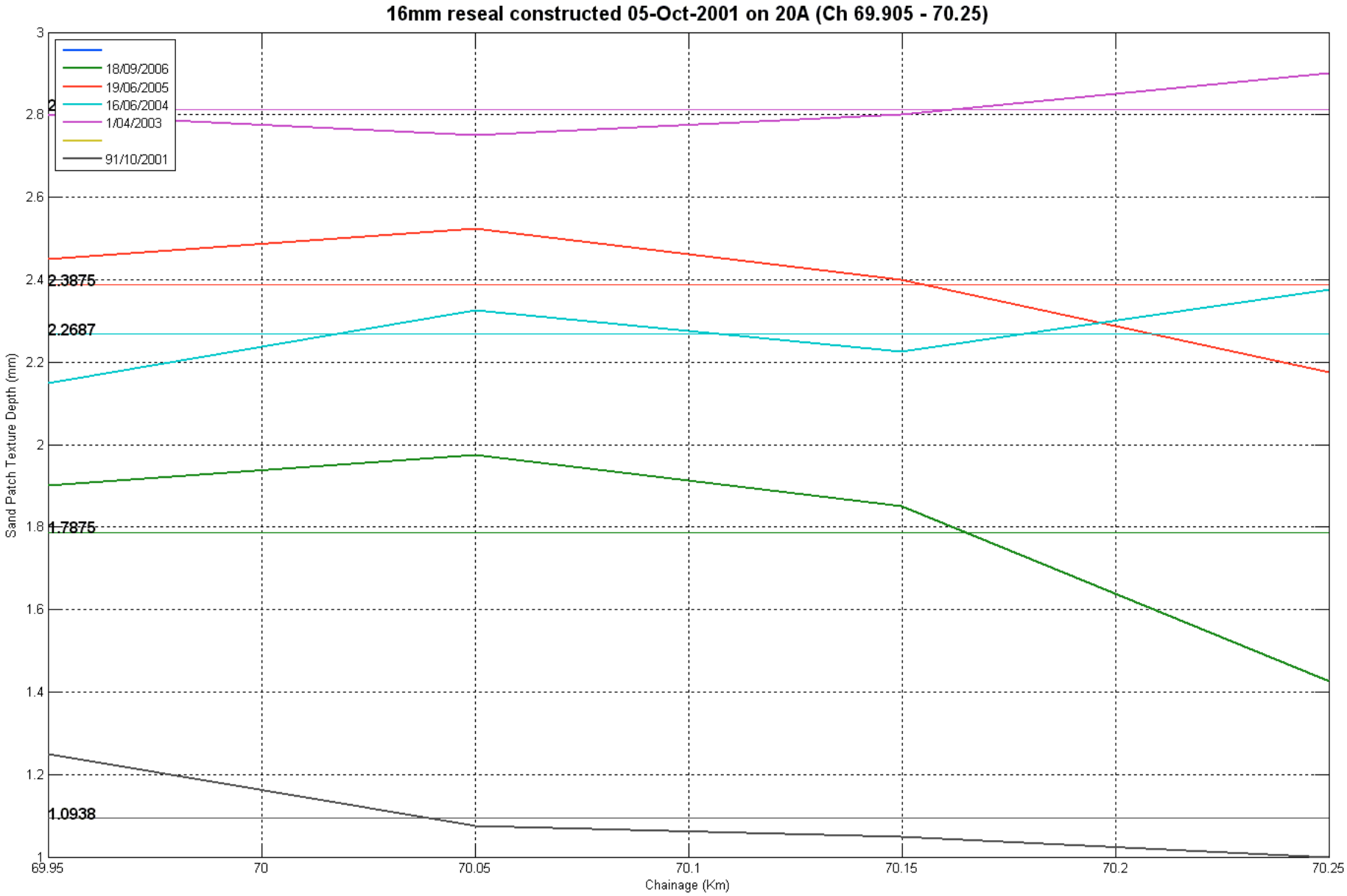

16mm reseal constructed 11-Aug-2008 on 20A (Ch 74.18 - 74.33)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
Sand Patch Texture Depth (mm)
Chainage (Km)
1.8833
1.725
1.6667
1.275
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
74.15
74.2
74.25
74.3

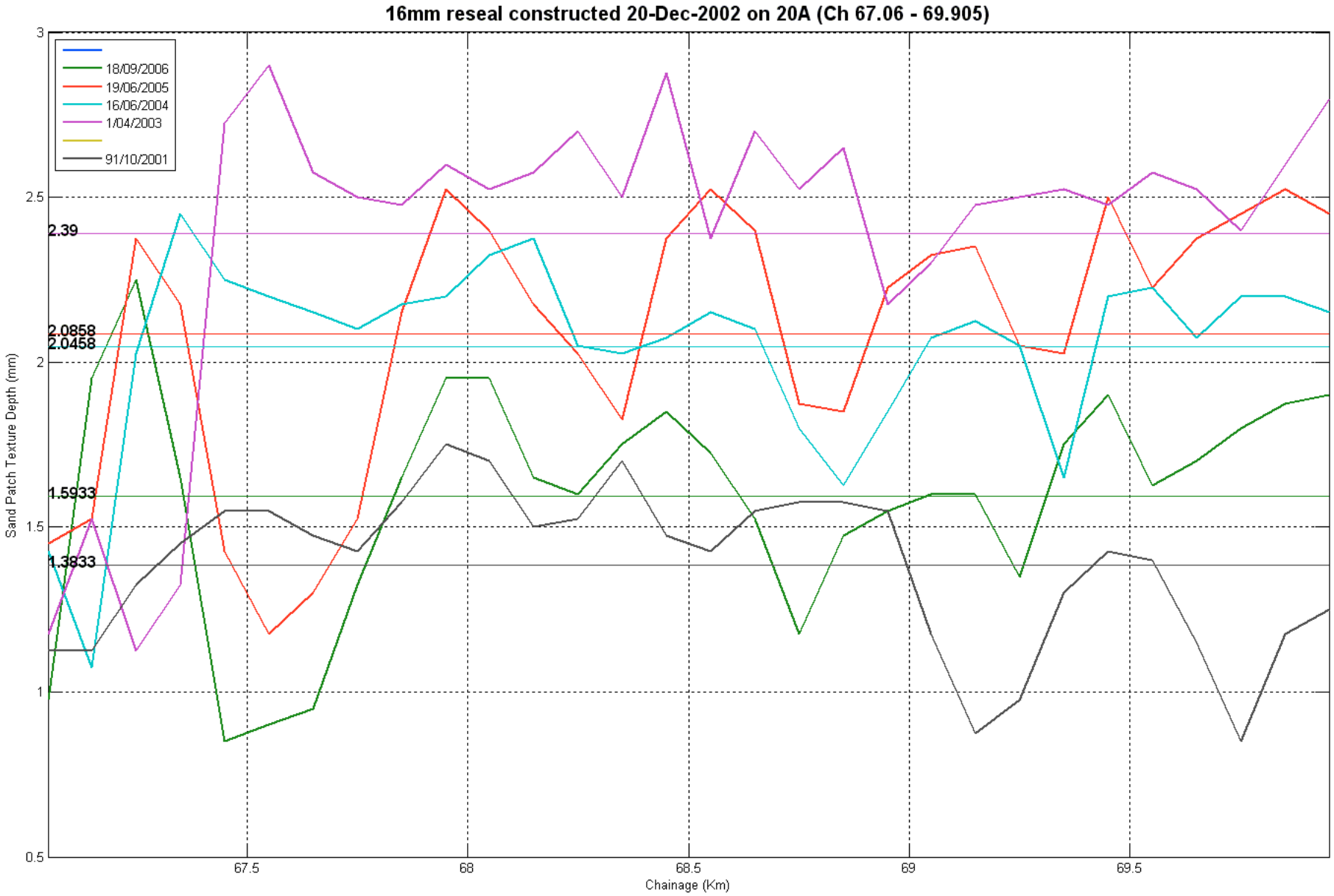

16mm reseal constructed 28-Sep-2006 on 20A (Ch 64.1 - 74.18)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
Sand Patch Texture Depth (mm)
Chainage (Km)
1.8934
1.8706
1.7123
1.6311
1.3806
3
2.5
2
1.5
1
0.5
65
66
67
68
69
70
71
72
73
74

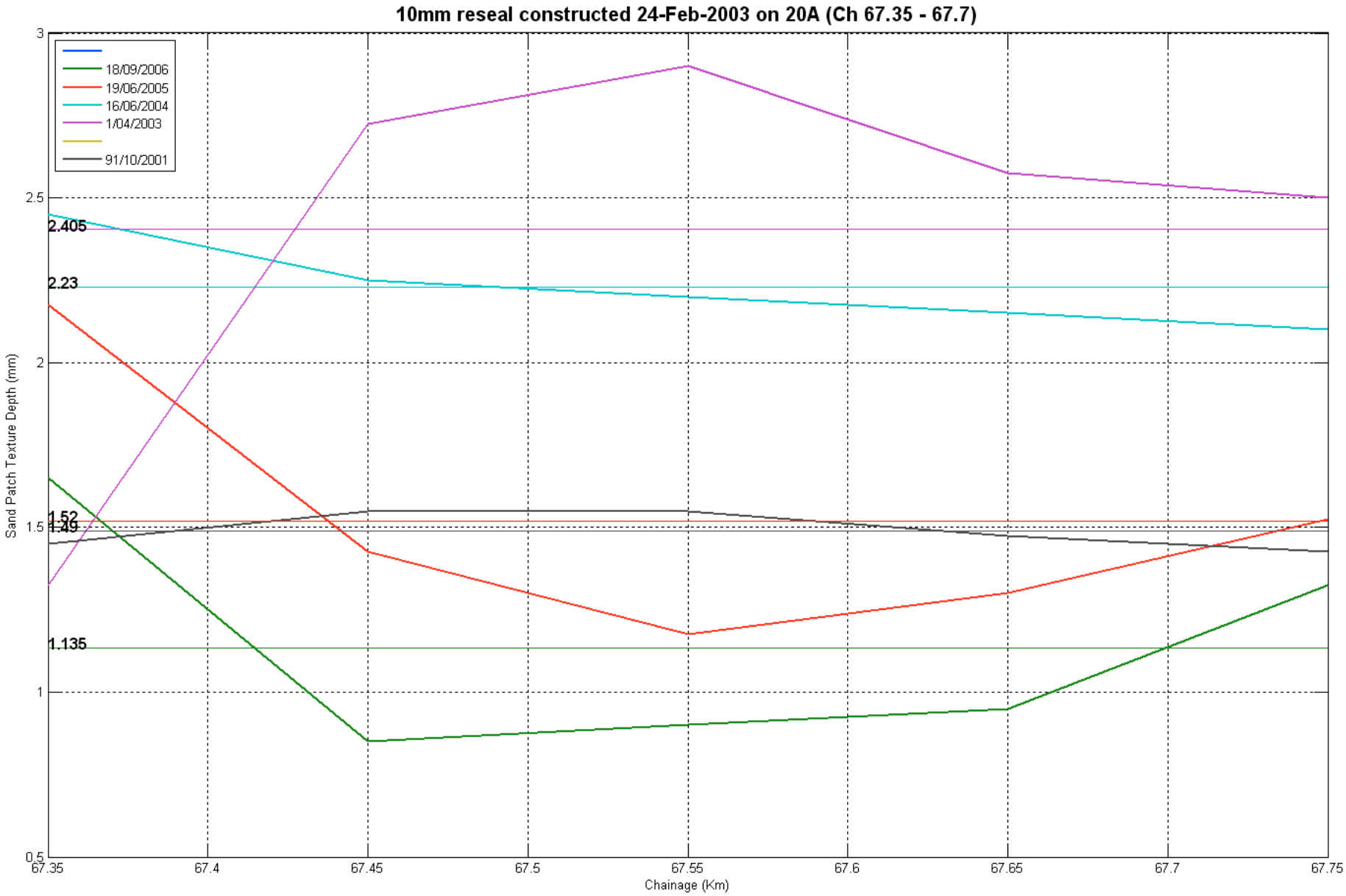

16mm reseal constructed 10-Dec-2002 on 20A (Ch 73.78 - 74.03)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
2.2625
2.025
1.8938
1.575
1.3062
Sand Patch Texture Depth (mm)
Chainage (Km)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
73.75
73.8
73.85
73.9
73.95
74
74.05

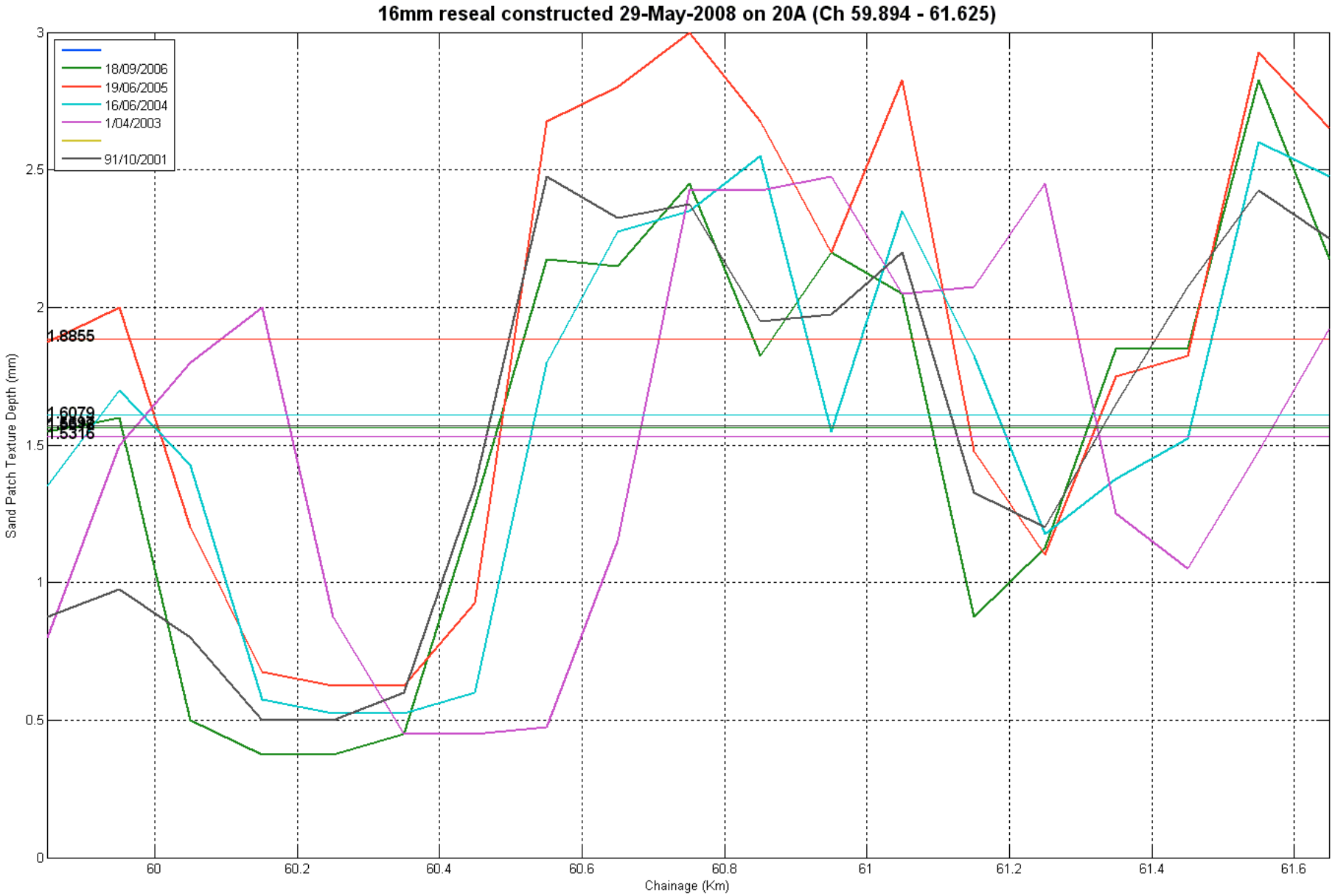

14mm reseal constructed 12-Nov-2005 on 20A (Ch 72.54 - 73.78)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
2.1096
1.6288
1.3962
1.3519
1.2769
Sand Patch Texture Depth (mm)
Chainage (Km)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
72.6
72.8
73
73.2
73.4
73.6

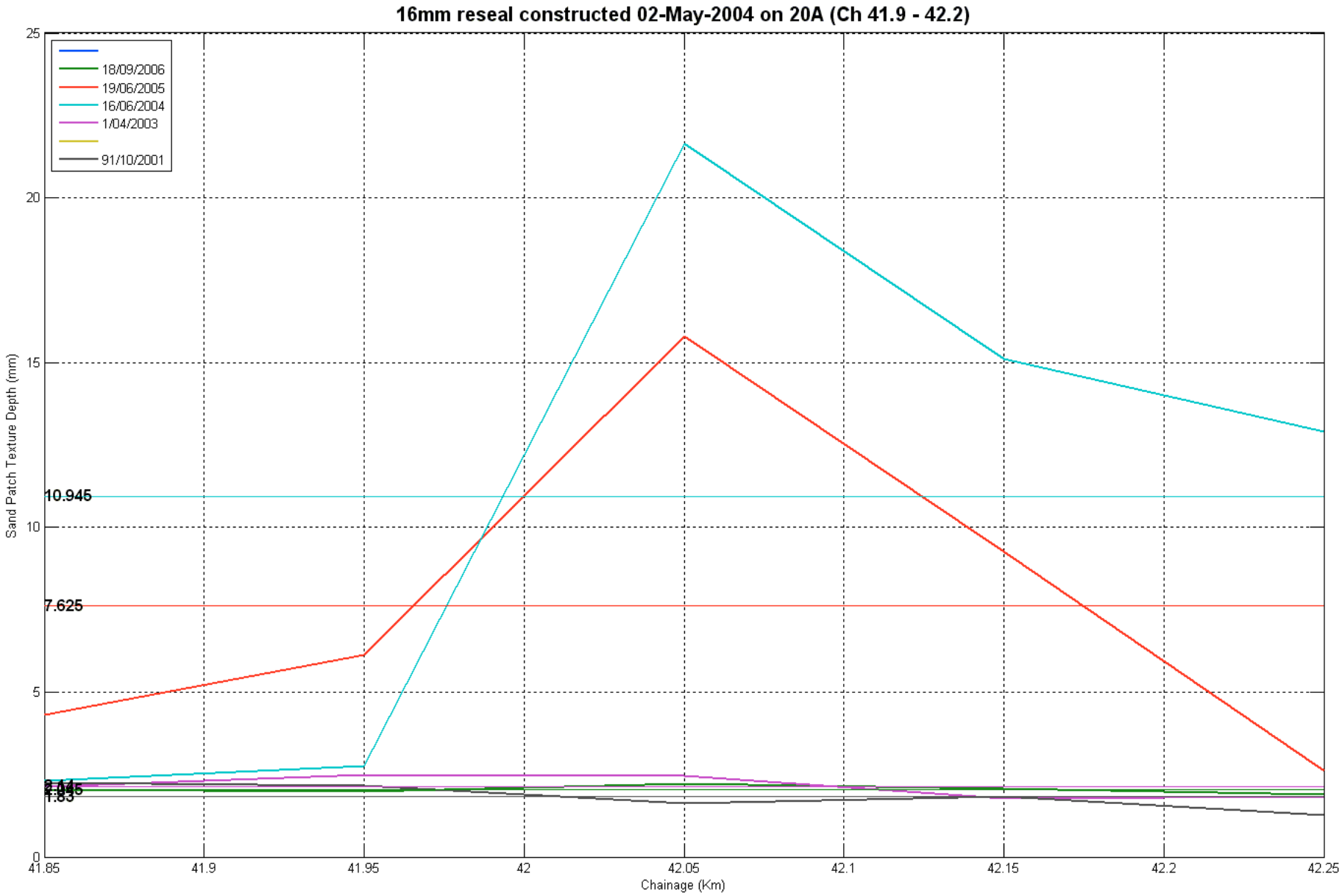

7mm reseal constructed 20-Dec-2002 on 20A (Ch 71.86 - 72.28)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
2.225
2.175
1.91
1.675
0.885
Sand Patch Texture Depth (mm)
Chainage (Km)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
71.85
71.9
71.95
72
72.05
72.1
72.15
72.2
72.25

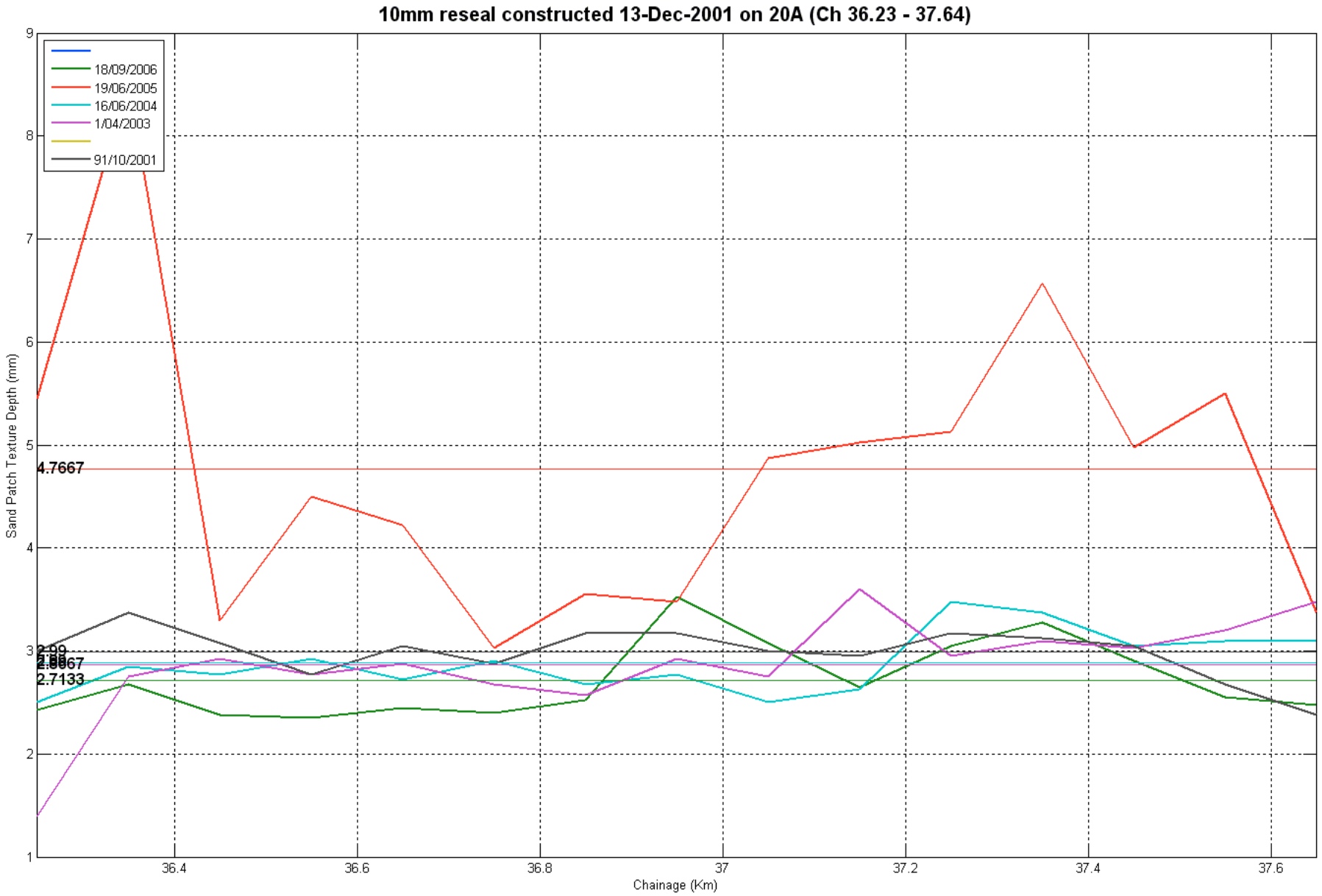

16mm reseal constructed 05-Oct-2001 on 20A (Ch 69.905 - 70.25)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
2
2.3875
2.2687
1.7875
1.0938
Sand Patch Texture Depth (mm)
Chainage (Km)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
69.95
70
70.05
70.1
70.15
70.2
70.25

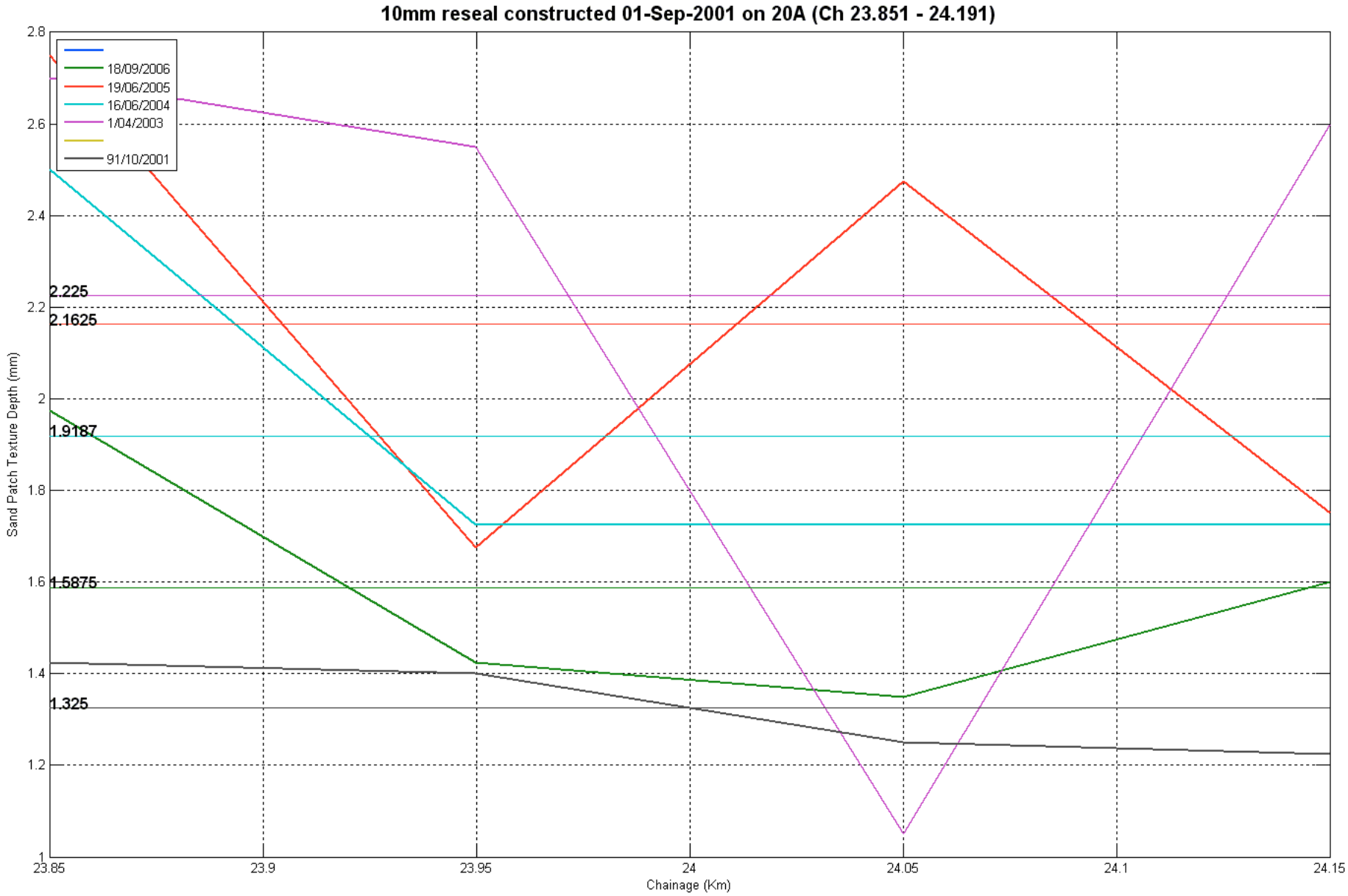

16mm reseal constructed 20-Dec-2002 on 20A (Ch 67.06 - 69.905)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
2.39
2.0858
2.0458
1.5933
1.3833
Sand Patch Texture Depth (mm)
Chainage (Km)
3
2.5
2
1.5
1
0.5
67.5
68
68.5
69
69.5

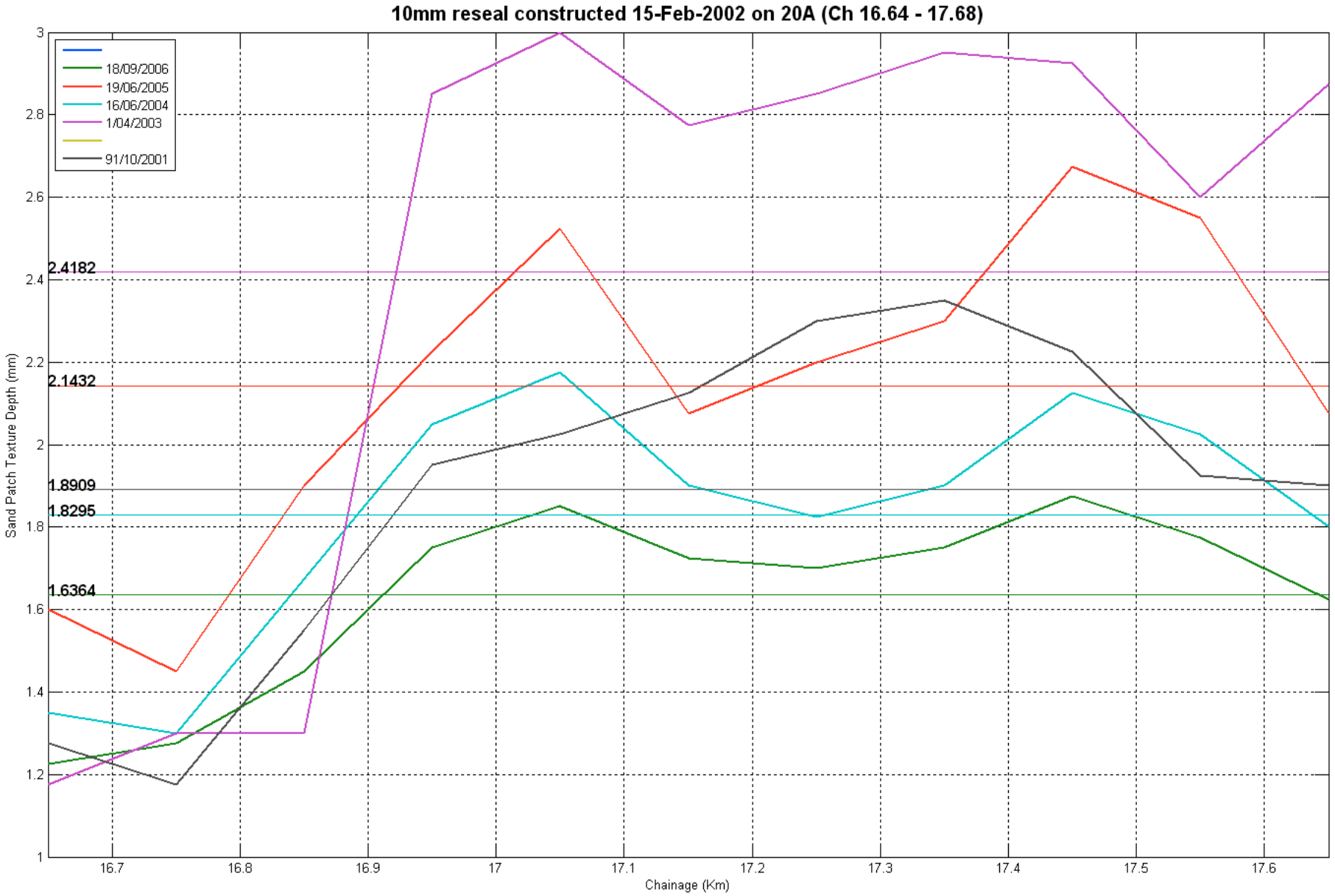

10mm reseal constructed 24-Feb-2003 on 20A (Ch 67.35 - 67.7)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
2.405
2.23
1.52
1.49
1.135
Sand Patch Texture Depth (mm)
Chainage (Km)
3
2.5
2
1.5
1
0.5
67.35
67.4
67.45
67.5
67.55
67.6
67.65
67.7
67.75

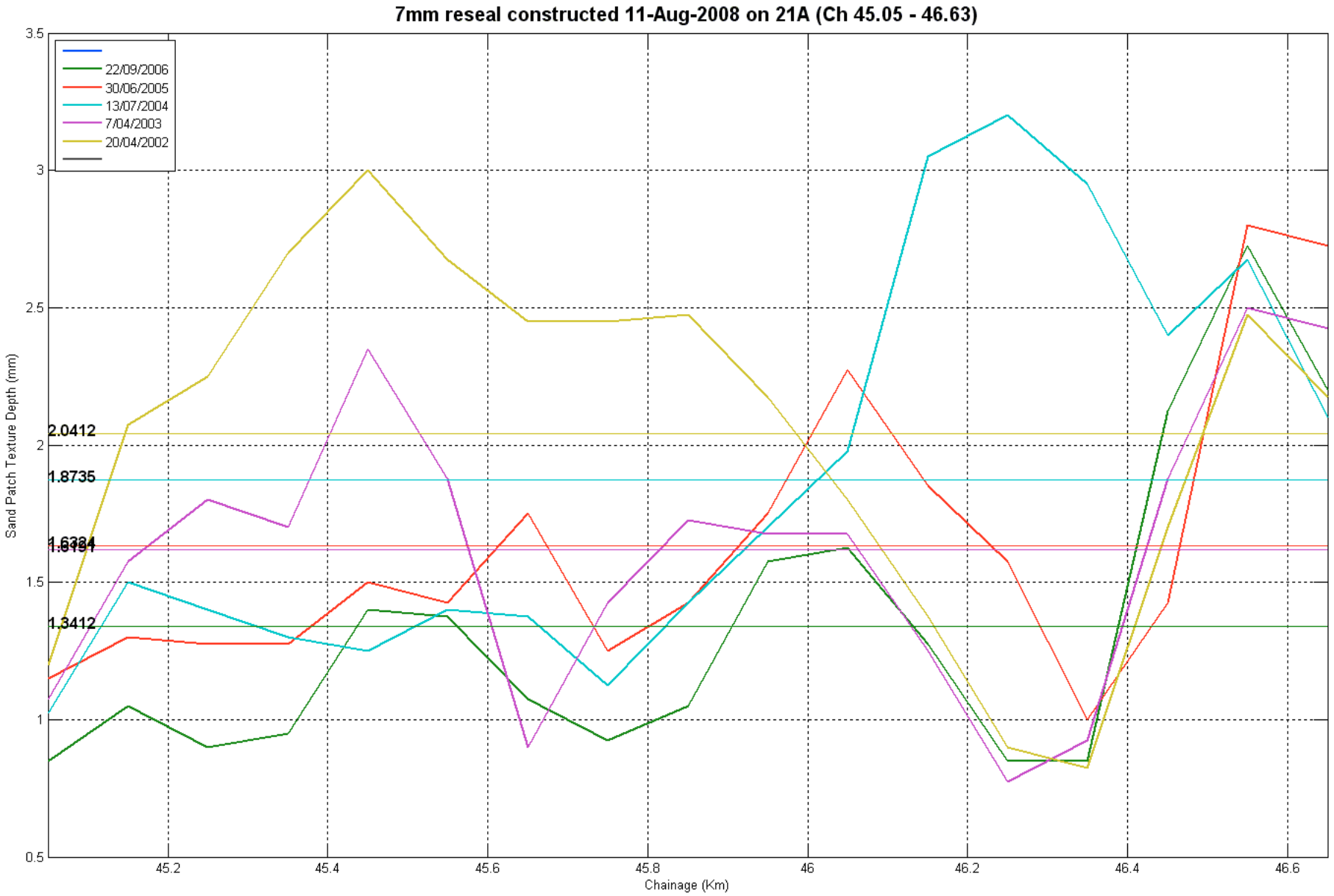

16mm reseal constructed 29-May-2008 on 20A (Ch 59.894 - 61.625)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
1.8855
1.6079
1.5316
Sand Patch Texture Depth (mm)
Chainage (Km)
0
0.5
1
1.5
2
2.5
3
60
60.2
60.4
60.6
60.8
61
61.2
61.4
61.6

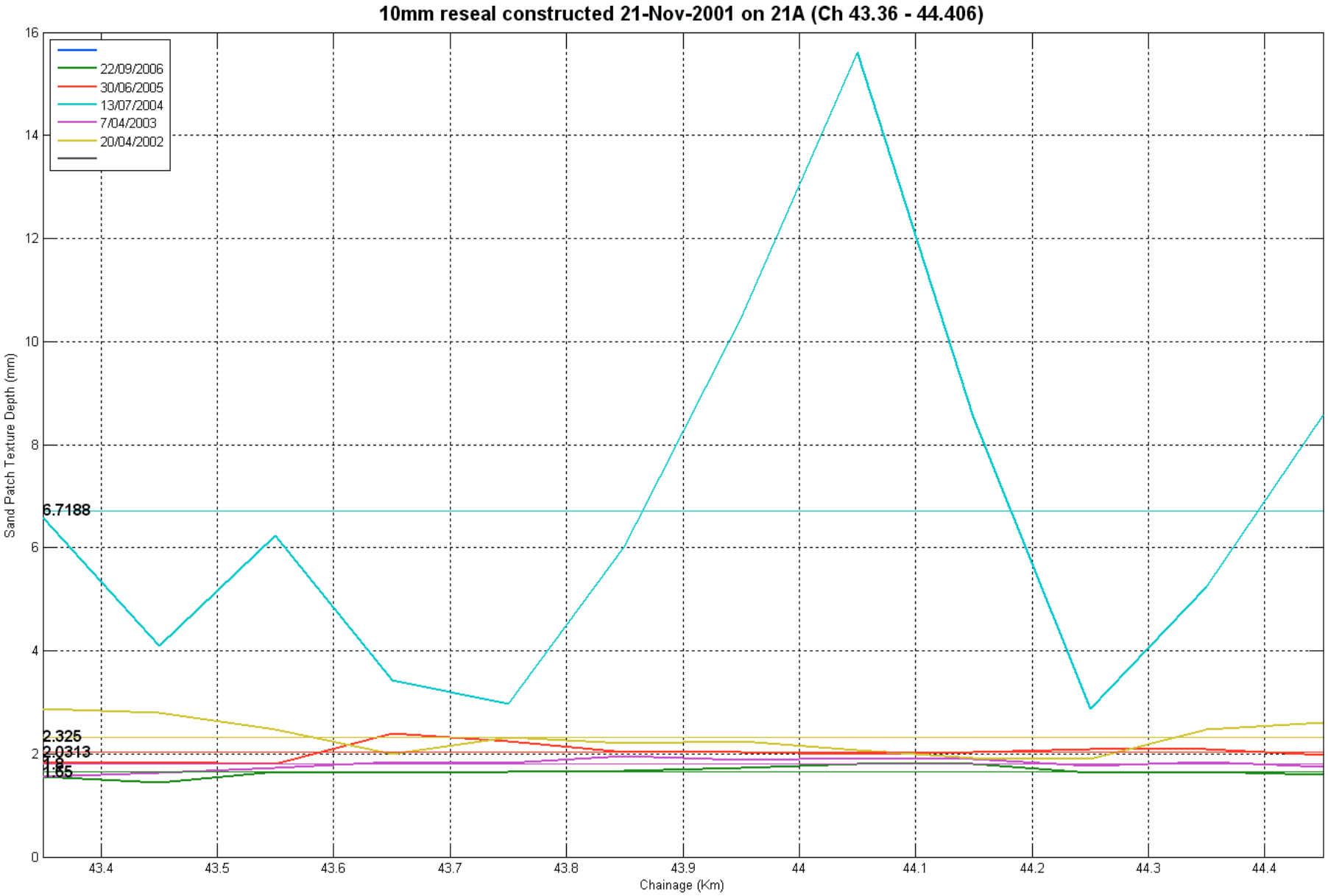

16mm reseal constructed 02-May-2004 on 20A (Ch 41.9 - 42.2)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
Sand Patch Texture Depth (mm)
Chainage (Km)
10.945
7.625
25
20
15
10
5
0
41.85
41.9
41.95
42
42.05
42.1
42.15
42.2
42.25

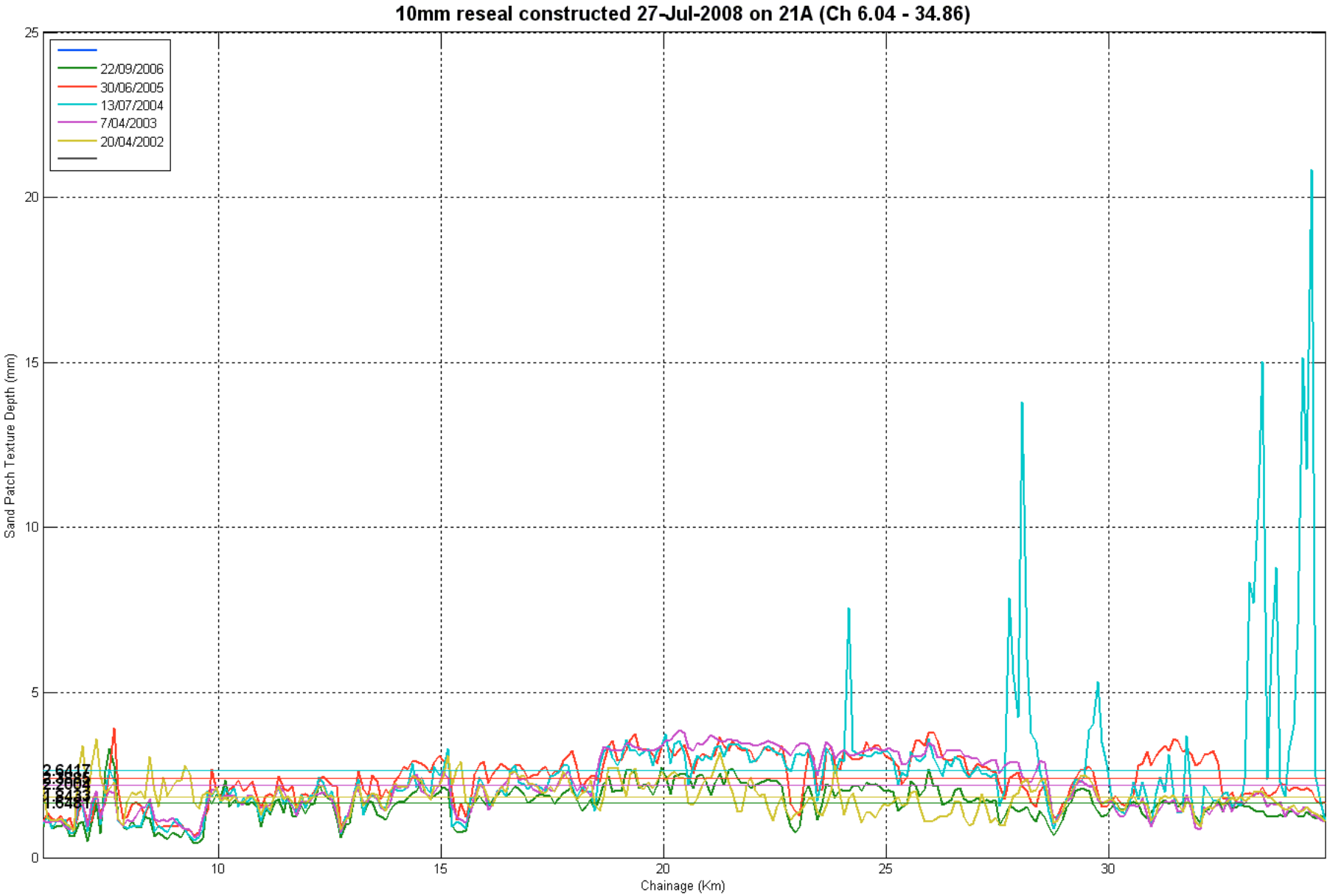

10mm reseal constructed 13-Dec-2001 on 20A (Ch 36.23 - 37.64)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
Sand Patch Texture Depth (mm)
Chainage (Km)
4.7667
2.99
2.7133
9
8
7
6
5
4
3
2
1
36.4
36.6
36.8
37
37.2
37.4
37.6

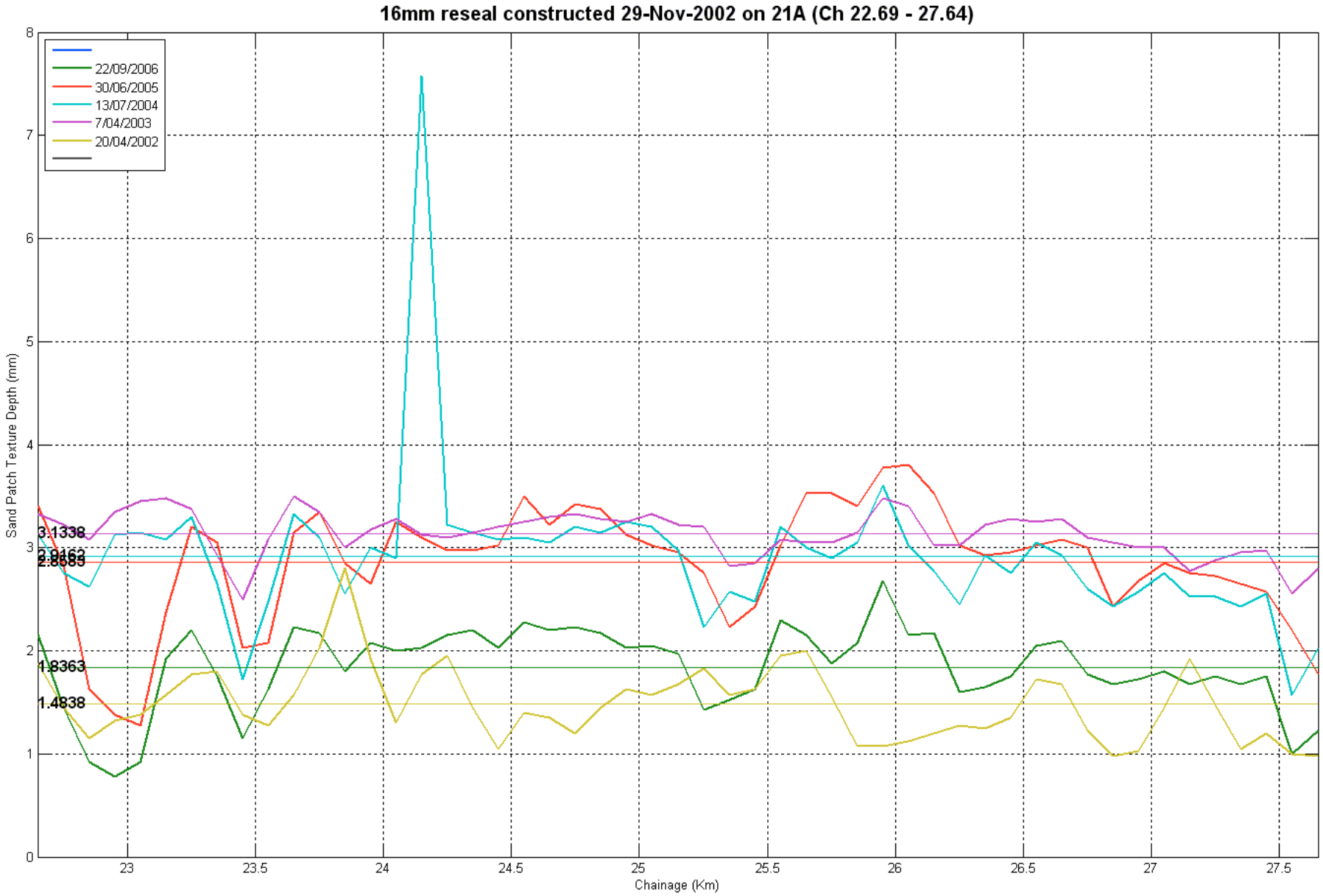

10mm reseal constructed 01-Sep-2001 on 20A (Ch 23.851 - 24.191)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
2.225
2.1625
1.9187
1.5875
1.325
Sand Patch Texture Depth (mm)
Chainage (Km)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
23.85
23.9
23.95
24
24.05
24.1
24.15

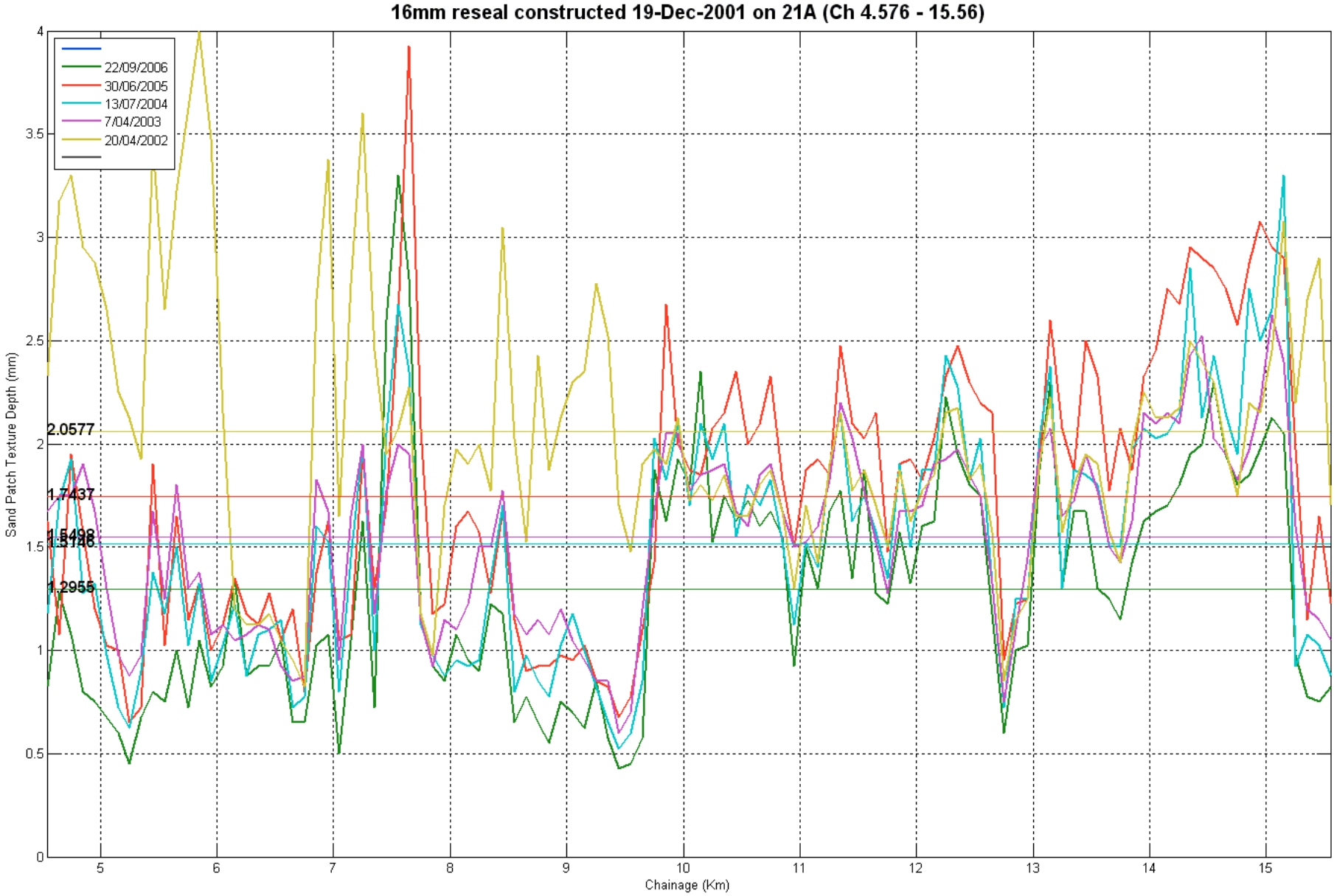

10mm reseal constructed 15-Feb-2002 on 20A (Ch 16.64 - 17.68)
18/09/2006
19/06/2005
16/06/2004
1/04/2003
91/10/2001
2.4182
2.1432
1.8909
1.8295
1.6364
Sand Patch Texture Depth (mm)
Chainage (Km)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
16.7
16.8
16.9
17
17.1
17.2
17.3
17.4
17.5
17.6

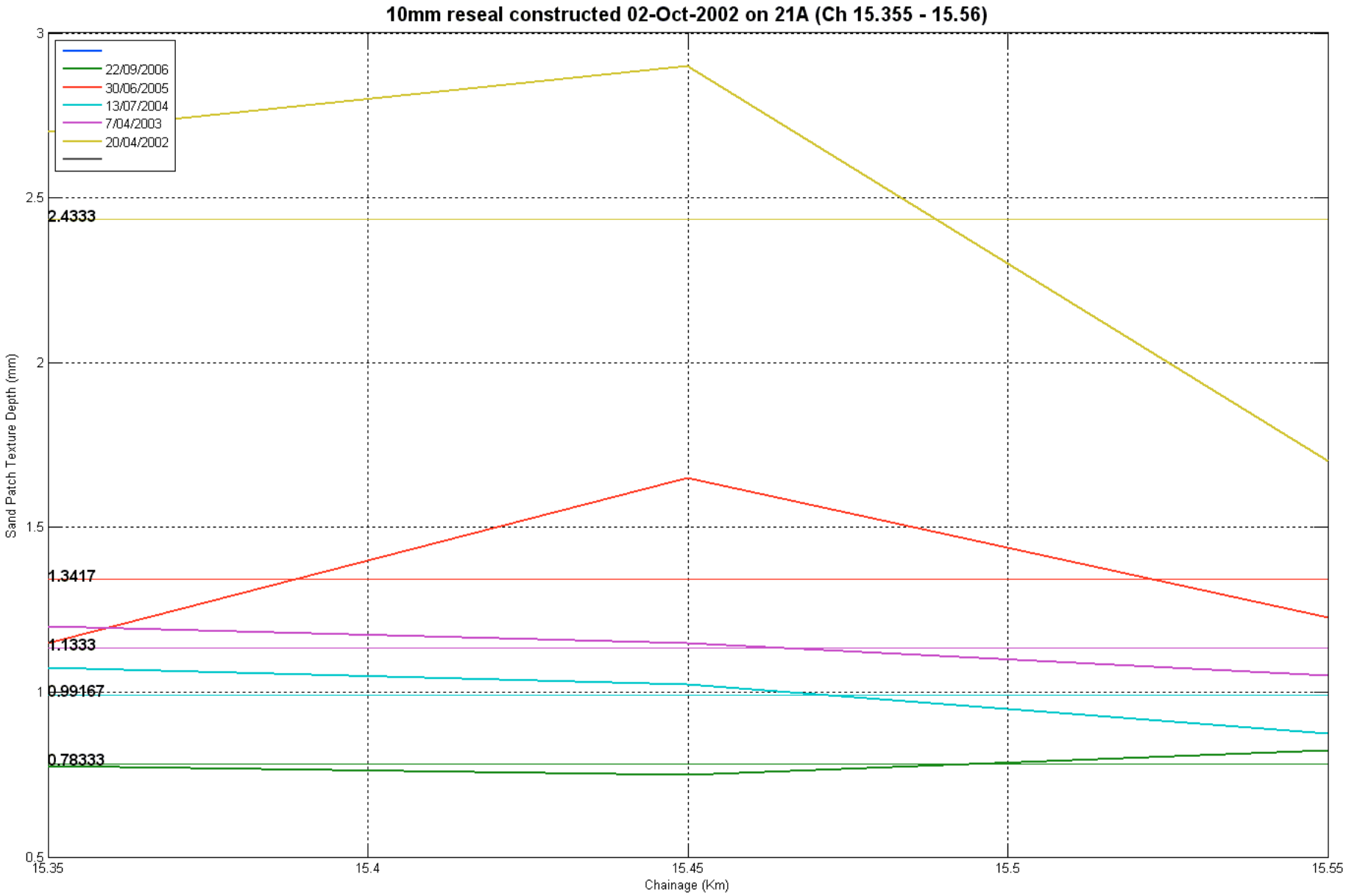

7mm reseal constructed 11-Aug-2008 on 21A (Ch 45.05 - 46.63)
22/09/2006
30/06/2005
13/07/2004
7/04/2003
20/04/2002
Sand Patch Texture Depth (mm)
Chainage (Km)
2.0412
1.8735
1.6384
1.6191
1.3412
3.5
3
2.5
2
1.5
1
0.5
45.2
45.4
45.6
45.8
46
46.2
46.4
46.6

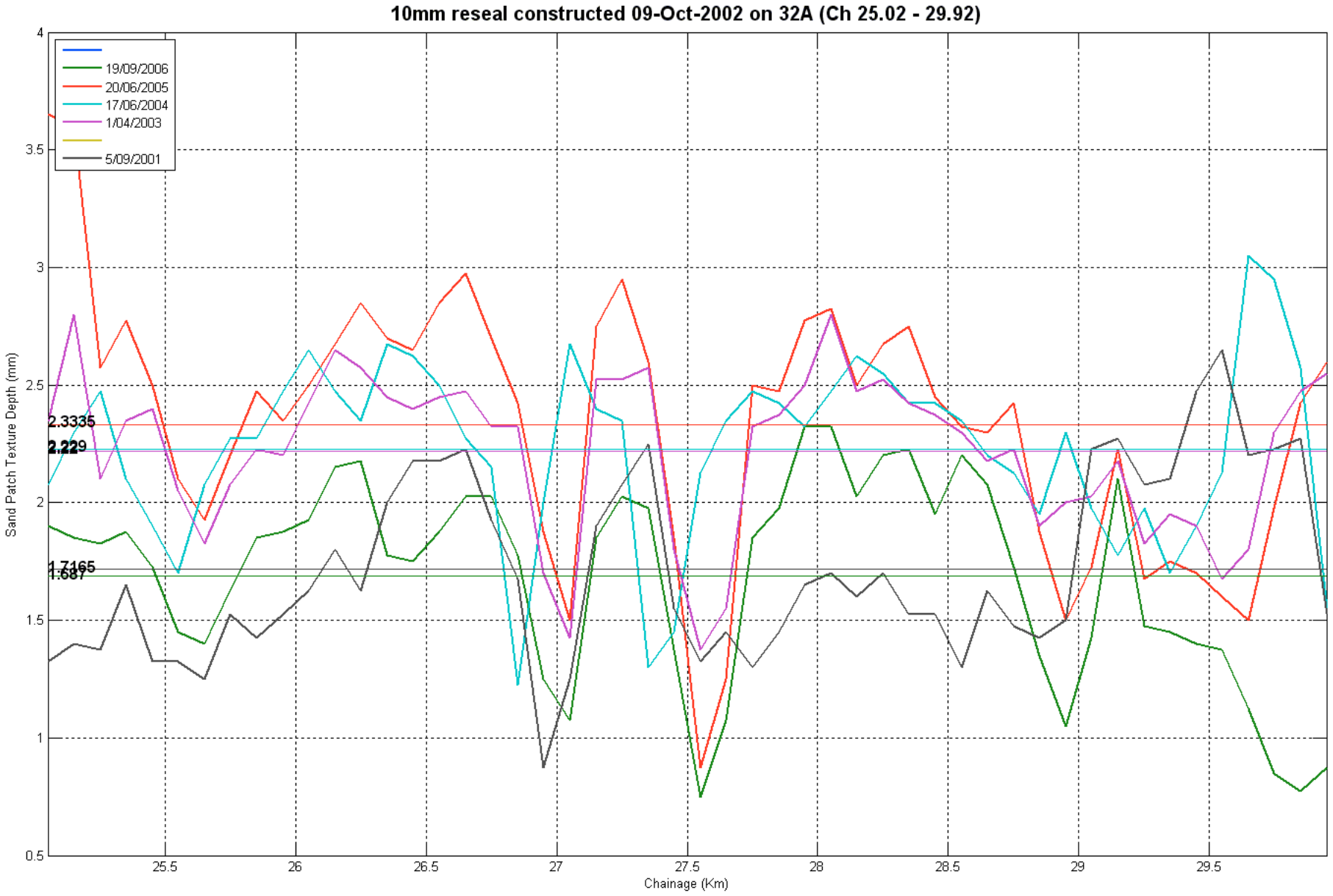

10mm reseal constructed 21-Nov-2001 on 21A (Ch 43.36 - 44.406)
22/09/2006
30/06/2005
13/07/2004
7/04/2003
20/04/2002
Sand Patch Texture Depth (mm)
Chainage (Km)
6.7188
2.325
2.0313
1.8
1.65
0
2
4
6
8
10
12
14
16
43.4
43.5
43.6
43.7
43.8
43.9
44
44.1
44.2
44.3
44.4

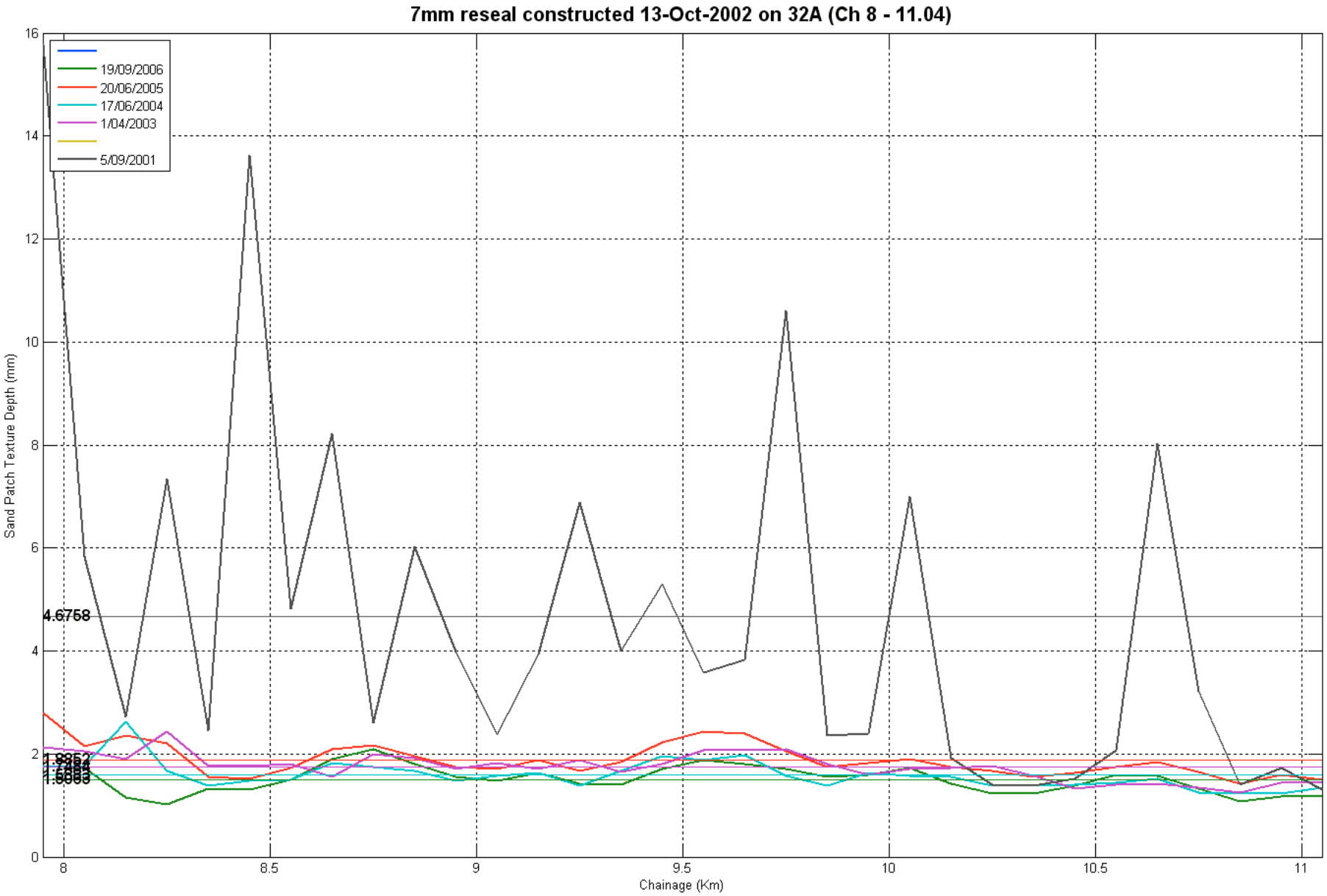

10mm reseal constructed 27-Jul-2008 on 21A (Ch 6.04 - 34.86)
22/09/2006
30/06/2005
13/07/2004
7/04/2003
20/04/2002
Sand Patch Texture Depth (mm)
Chainage (Km)
0
5
10
15
20
25
10
15
20
25
30

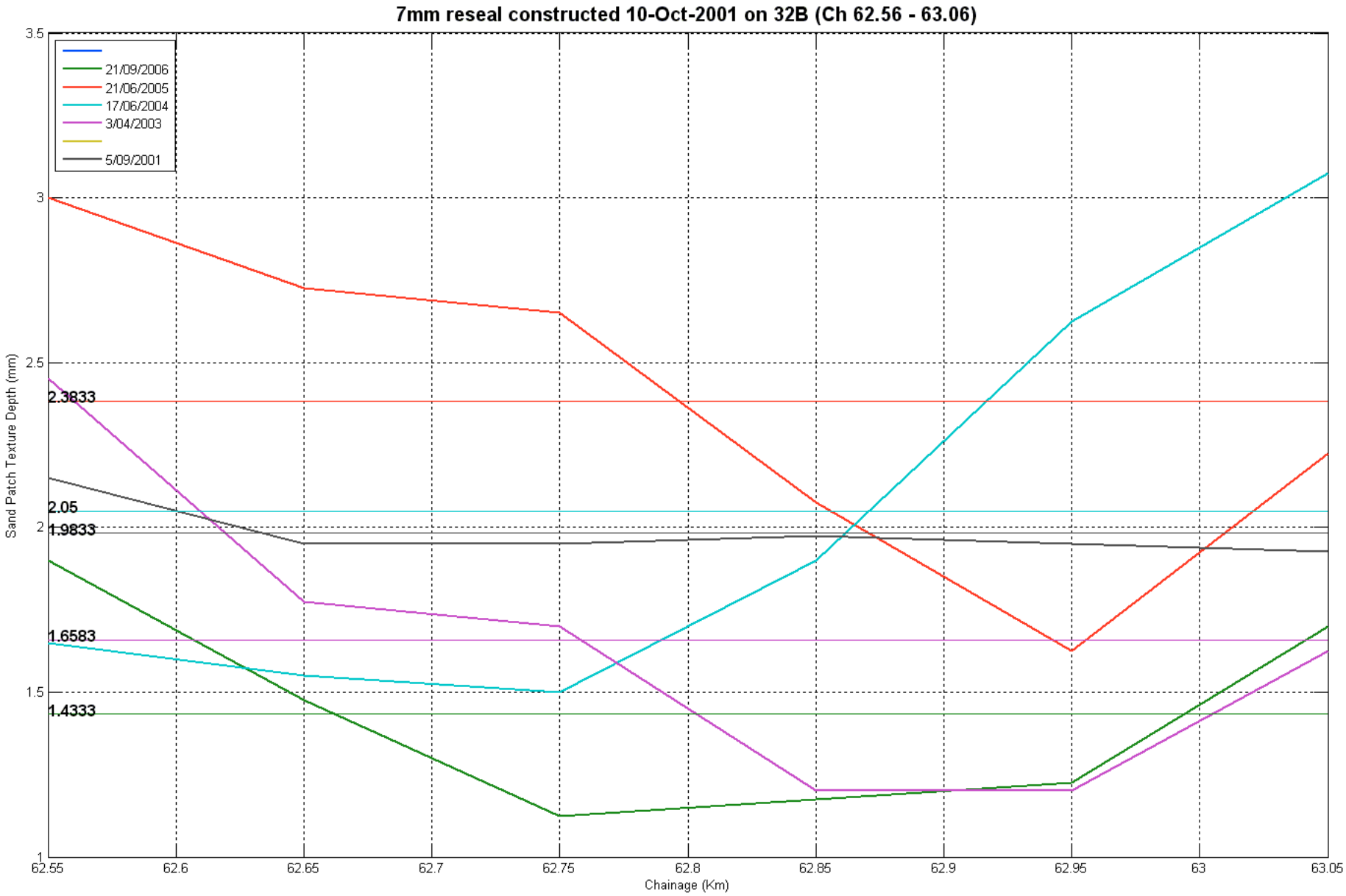

16mm reseal constructed 29-Nov-2002 on 21A (Ch 22.69 - 27.64)
22/09/2006
30/06/2005
13/07/2004
7/04/2003
20/04/2002
Sand Patch Texture Depth (mm)
Chainage (Km)
3.1338
2.9162
2.8589
1.8363
1.4838
0
1
2
3
4
5
6
7
8
23
23.5
24
24.5
25
25.5
26
26.5
27
27.5

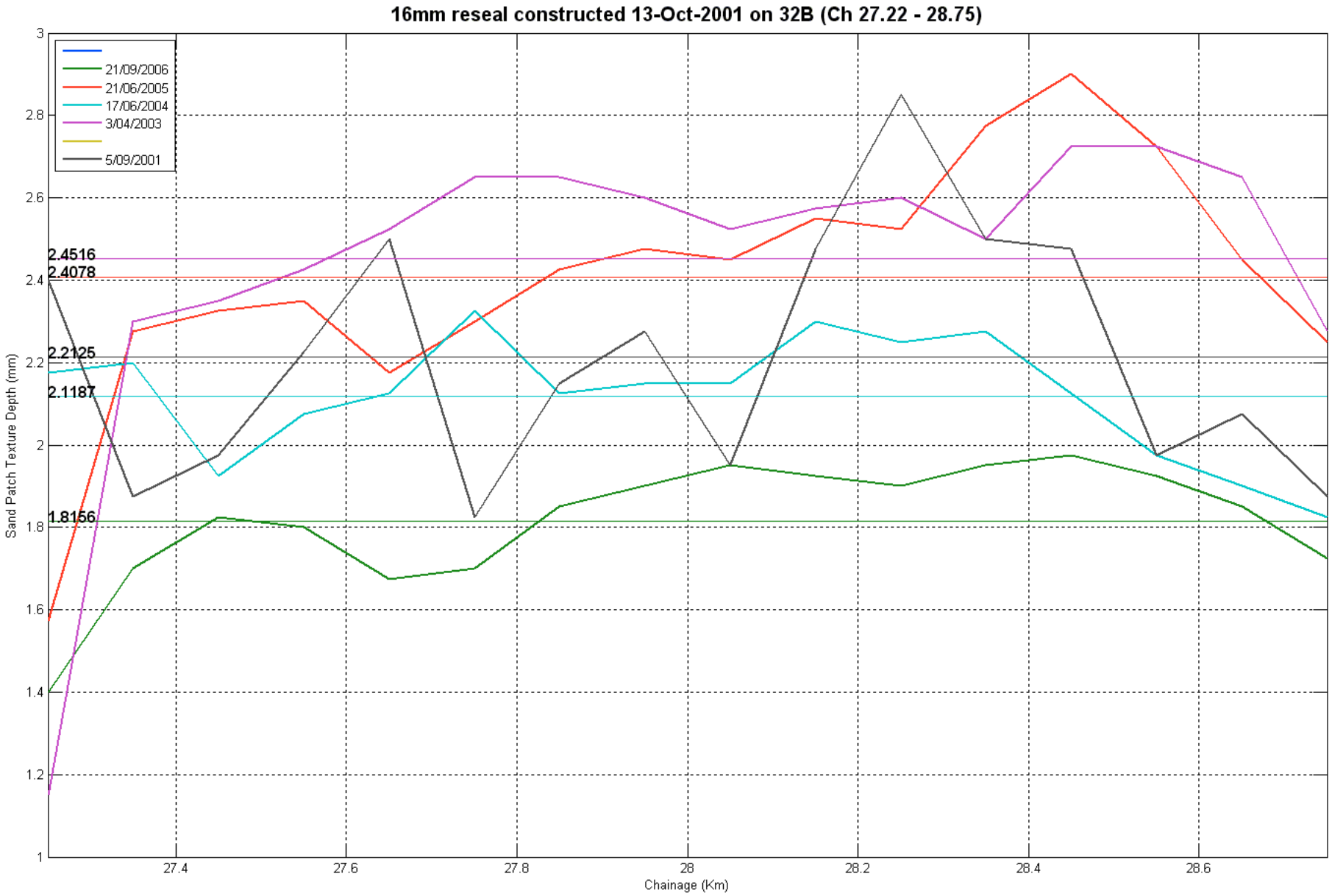

16mm reseal constructed 19-Dec-2001 on 21A (Ch 4.576 - 15.56)
22/09/2006
30/06/2005
13/07/2004
7/04/2003
20/04/2002
Sand Patch Texture Depth (mm)
Chainage (Km)
2.0577
1.7437
1.5498
1.5146
1.2955
0
0.5
1
1.5
2
2.5
3
3.5
4
5
6
7
8
9
10
11
12
13
14
15

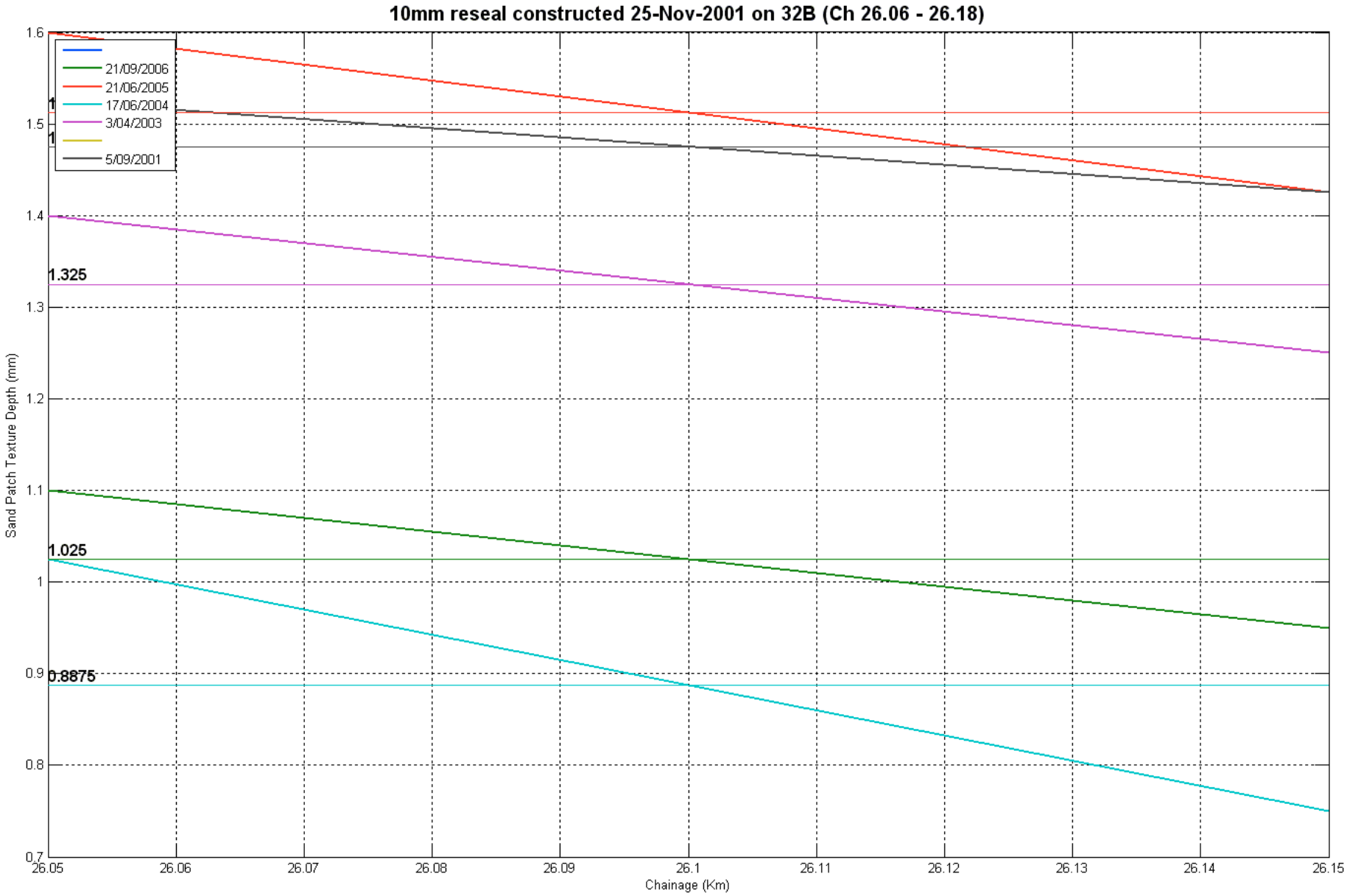

10mm reseal constructed 02-Oct-2002 on 21A (Ch 15.355 - 15.56)
22/09/2006
30/06/2005
13/07/2004
7/04/2003
20/04/2002
2.4333
1.3417
1.1333
0.99167
0.78333
Sand Patch Texture Depth (mm)
Chainage (Km)
3
2.5
2
1.5
1
0.5
15.35
15.4
15.45
15.5
15.55

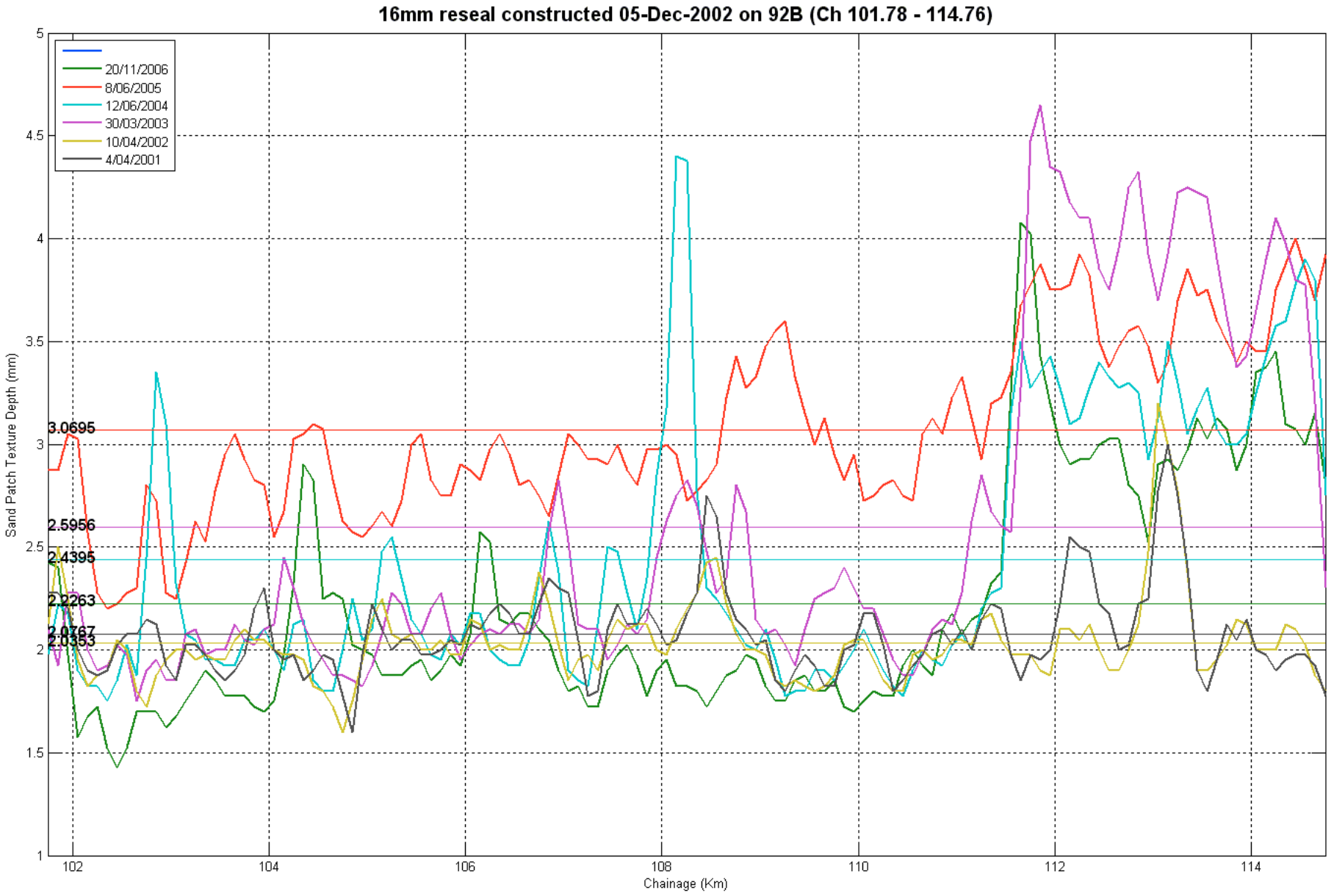

10mm reseal constructed 09-Oct-2002 on 32A (Ch 25.02 - 29.92)
19/09/2006
20/06/2005
17/06/2004
1/04/2003
5/09/2001
2.3335
2.229
1.7165
1.687
Sand Patch Texture Depth (mm)
Chainage (Km)
4
3.5
3
2.5
2
1.5
1
0.5
25.5
26
26.5
27
27.5
28
28.5
29
29.5

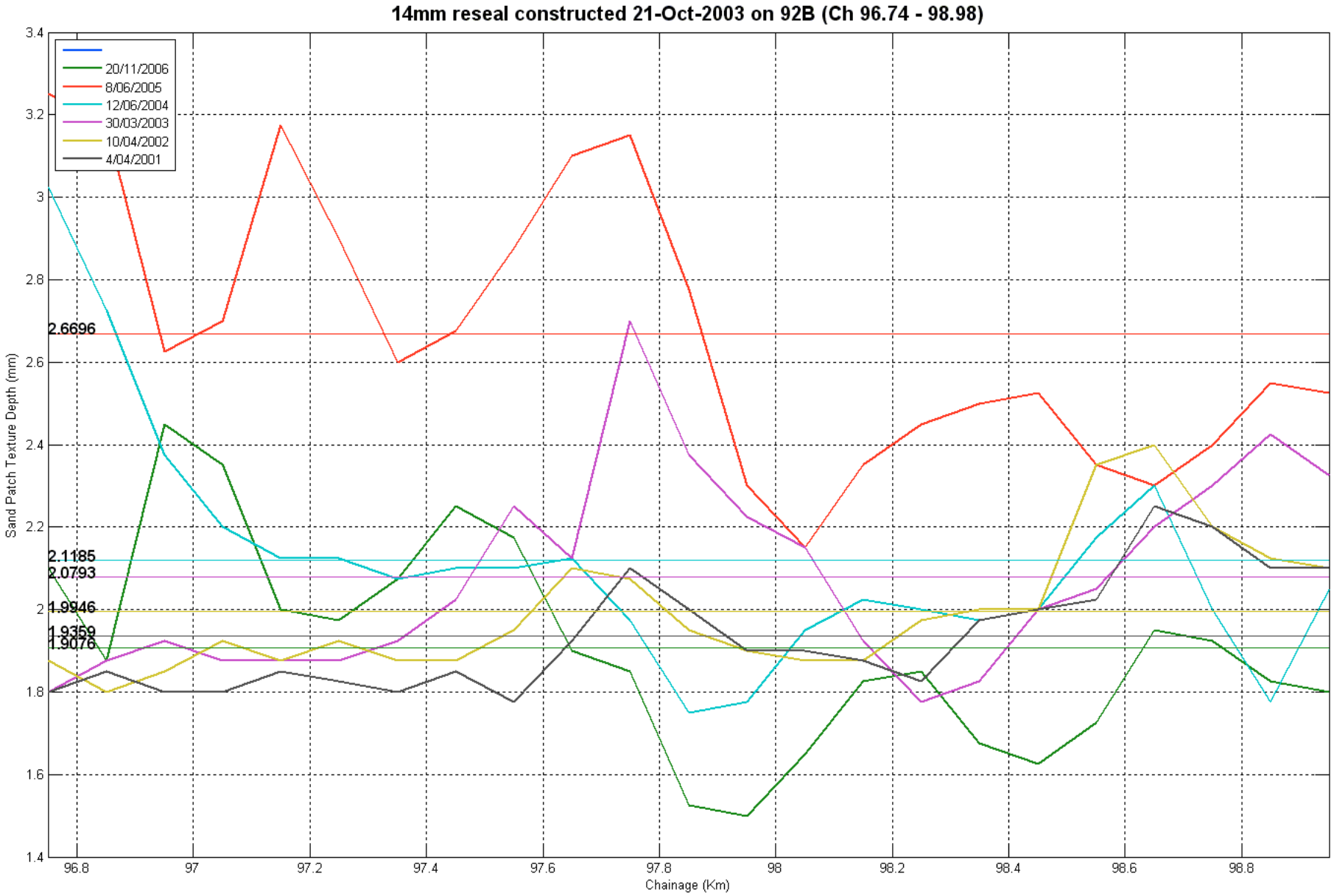

7mm reseal constructed 13-Oct-2002 on 32A (Ch 8 - 11.04)
19/09/2006
20/06/2005
17/06/2004
1/04/2003
5/09/2001
Sand Patch Texture Depth (mm)
Chainage (Km)
4.6758
1.8352
0
2
4
6
8
10
12
14
16
8
8.5
9
9.5
10
10.5
11

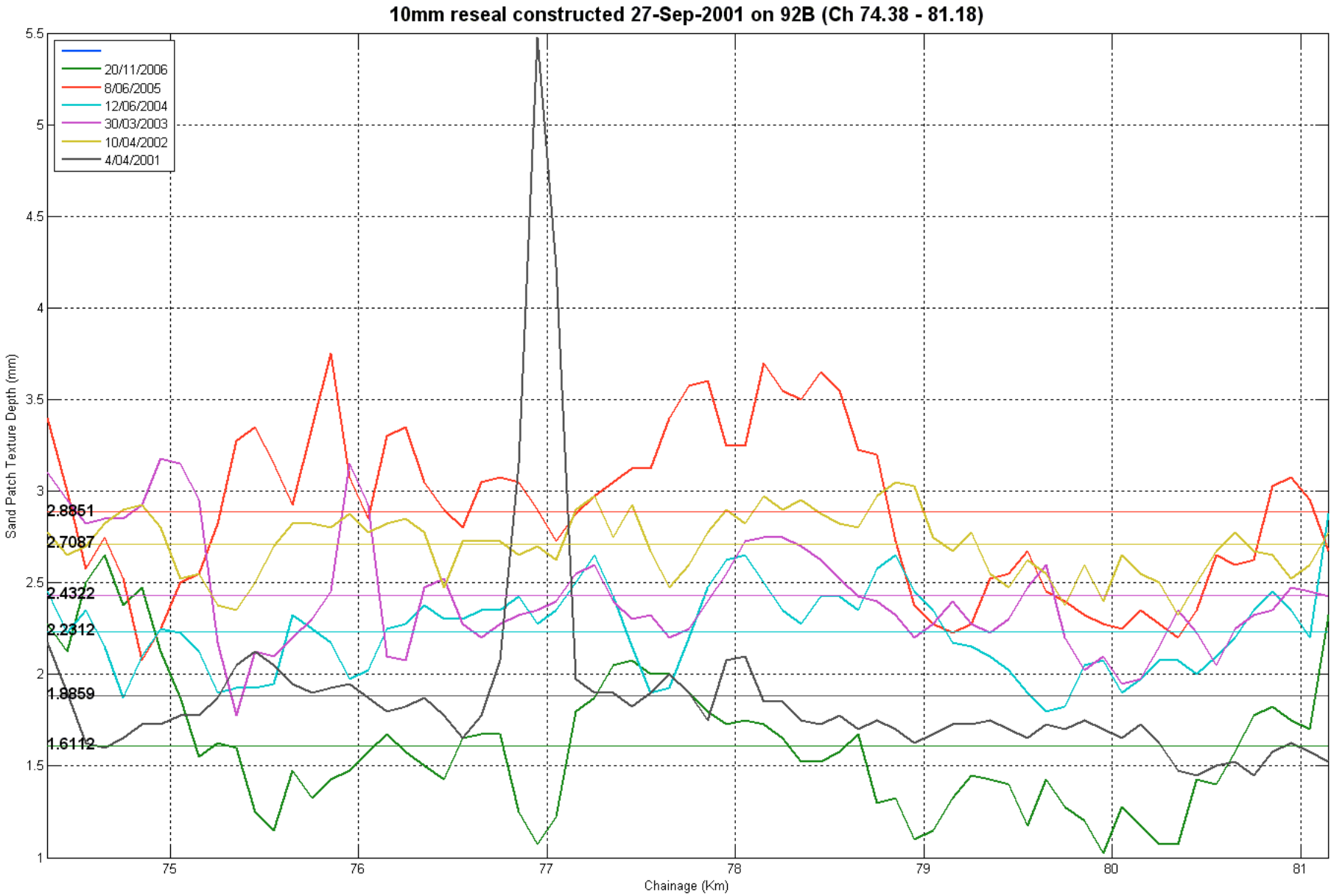

7mm reseal constructed 10-Oct-2001 on 32B (Ch 62.56 - 63.06)
21/09/2006
21/06/2005
17/06/2004
3/04/2003
5/09/2001
2.3833
2.05
1.9833
1.6583
1.4333
Sand Patch Texture Depth (mm)
Chainage (Km)
3.5
3
2.5
2
1.5
1
62.55
62.6
62.65
62.7
62.75
62.8
62.85
62.9
62.95
63
63.05

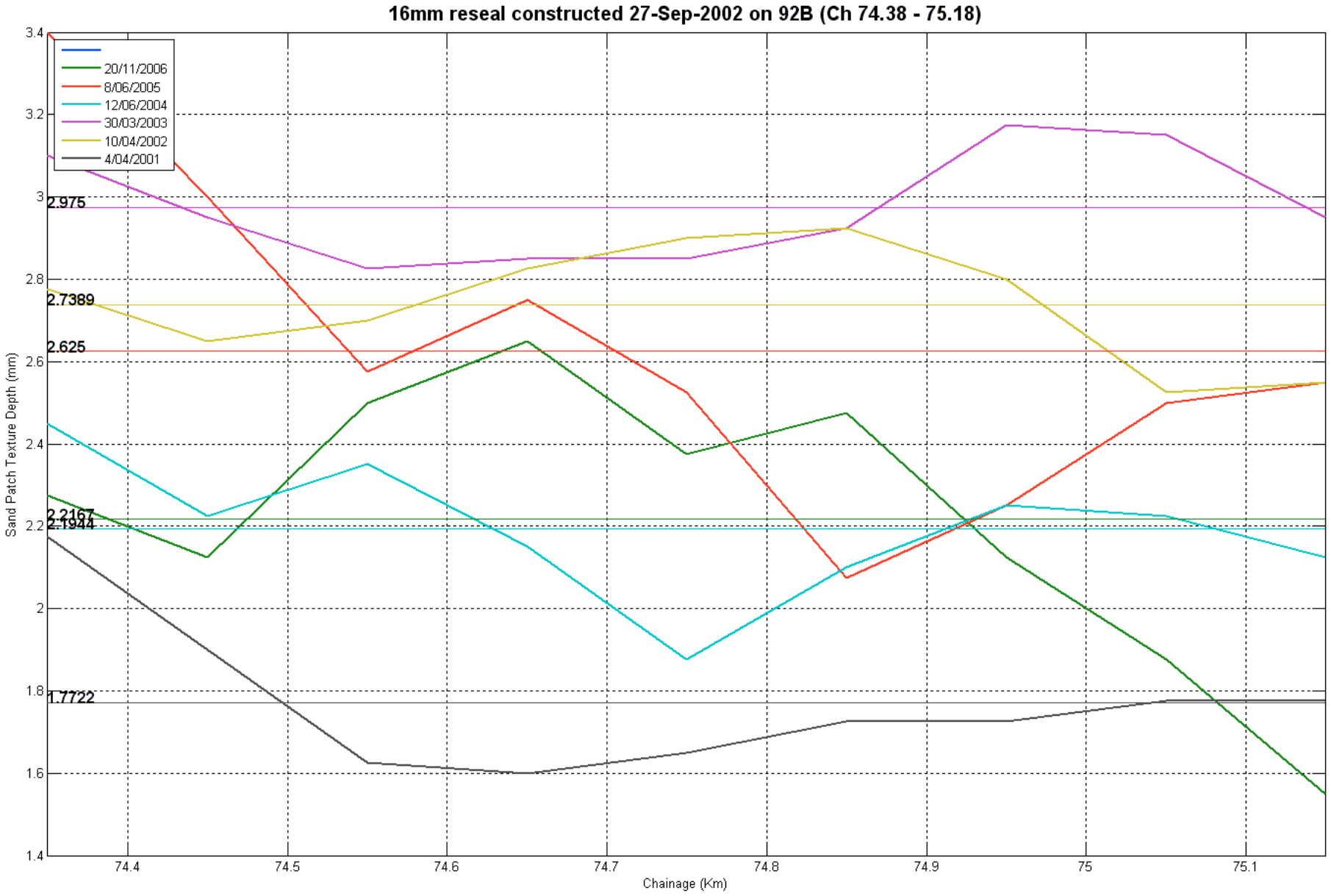

16mm reseal constructed 13-Oct-2001 on 32B (Ch 27.22 - 28.75)
21/09/2006
21/06/2005
17/06/2004
3/04/2003
5/09/2001
2.4516
2.4078
2.2125
2.1187
1.8156
Sand Patch Texture Depth (mm)
Chainage (Km)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
27.4
27.6
27.8
28
28.2
28.4
28.6

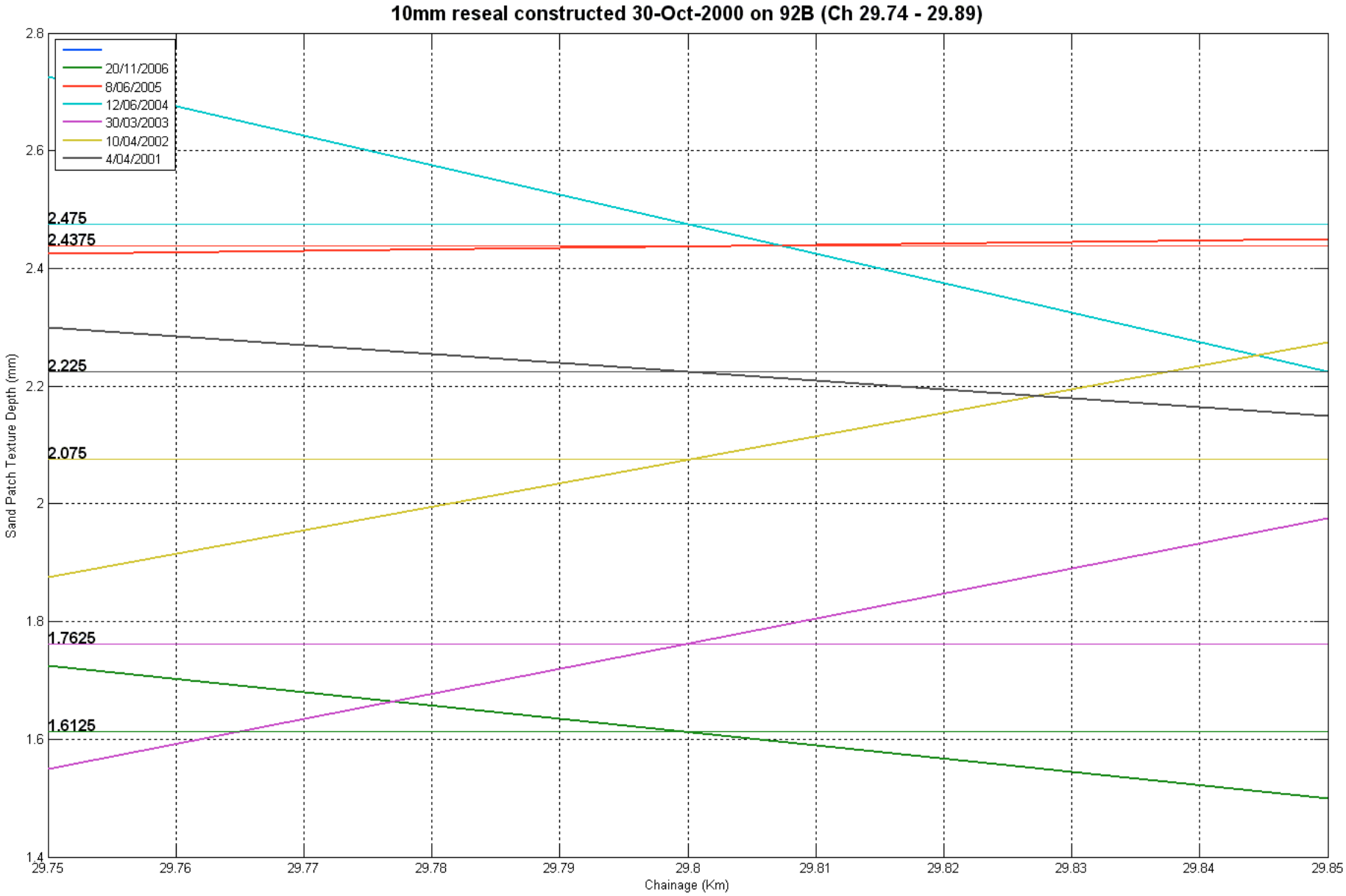

10mm reseal constructed 25-Nov-2001 on 32B (Ch 26.06 - 26.18)
21/09/2006
21/06/2005
17/06/2004
3/04/2003
5/09/2001
1.325
1.025
0.8875
Sand Patch Texture Depth (mm)
Chainage (Km)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
26.05
26.06
26.07
26.08
26.09
26.1
26.11
26.12
26.13
26.14
26.15

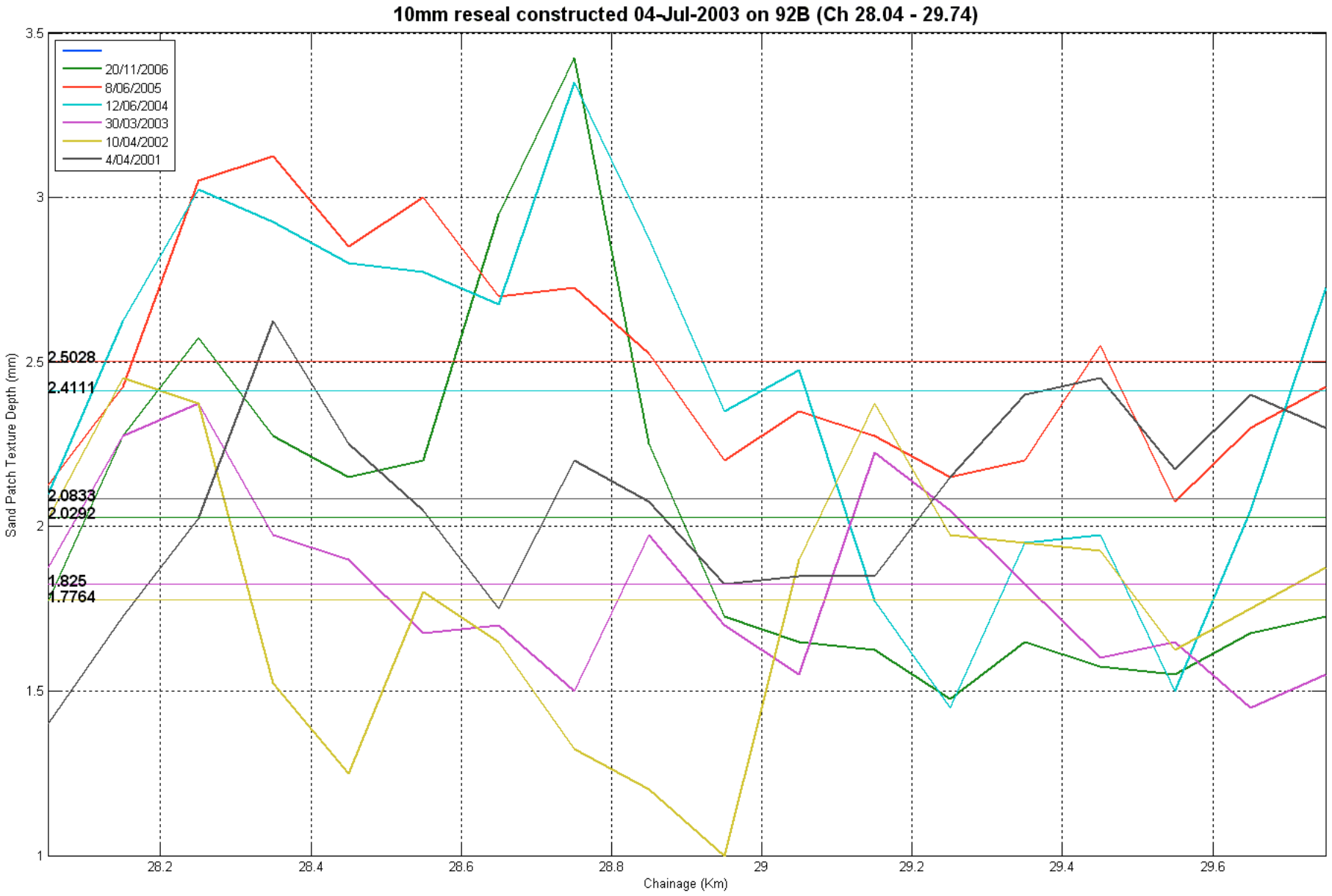

16mm reseal constructed 05-Dec-2002 on 92B (Ch 101.78 - 114.76)
20/11/2006
8/06/2005
12/06/2004
30/03/2003
10/04/2002
4/04/2001
3.0695
2.5956
2.4395
2.2263
2.0767
2.0353
Sand Patch Texture Depth (mm)
Chainage (Km)
5
4.5
4
3.5
3
2.5
2
1.5
1
102
104
106
108
110
112
114

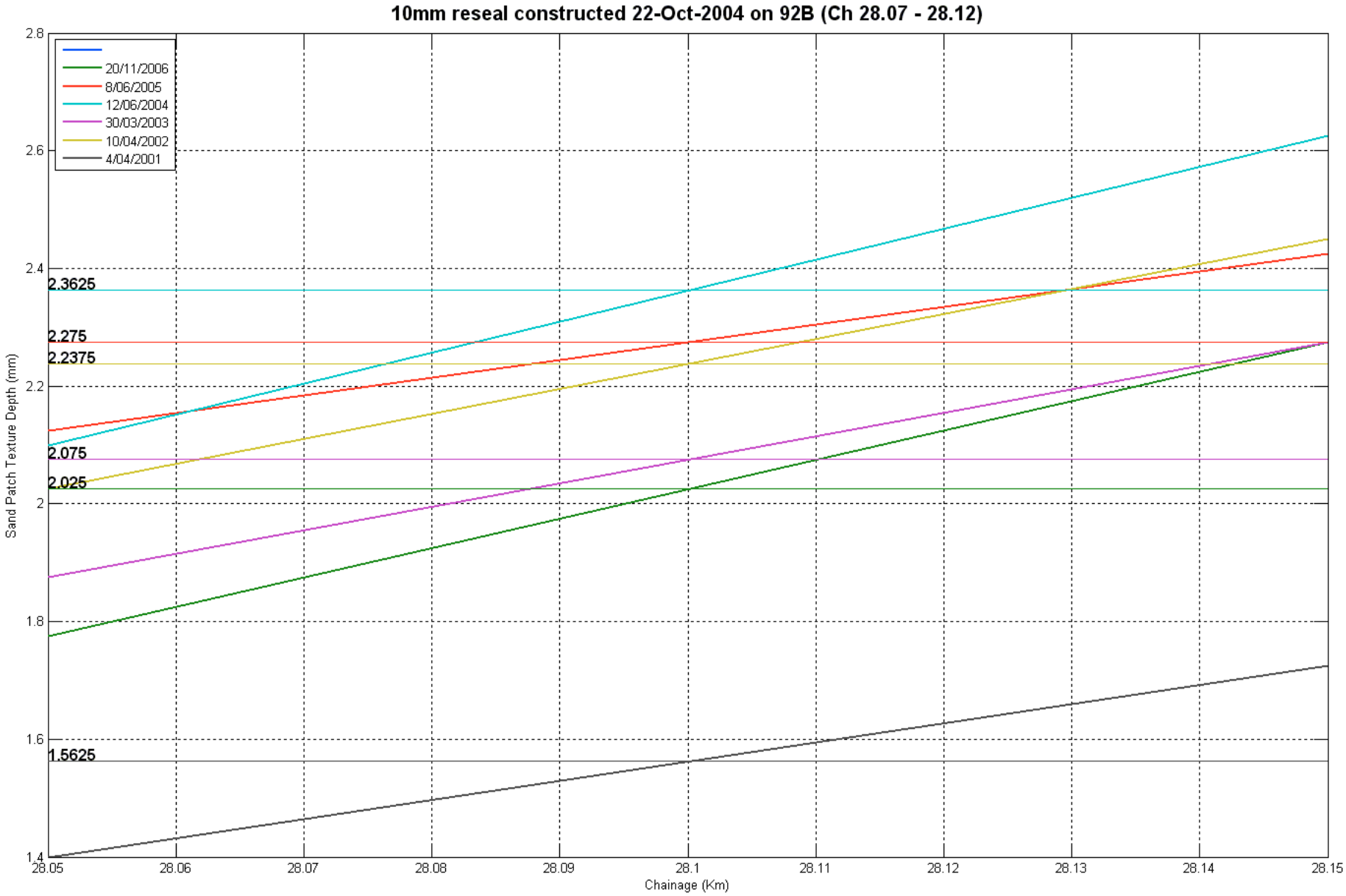

14mm reseal constructed 21-Oct-2003 on 92B (Ch 96.74 - 98.98)
20/11/2006
8/06/2005
12/06/2004
30/03/2003
10/04/2002
4/04/2001
2.6696
2.1185
2.0793
1.9946
1.9359
1.9076
Sand Patch Texture Depth (mm)
Chainage (Km)
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
96.8
97
97.2
97.4
97.6
97.8
98
98.2
98.4
98.6
98.8

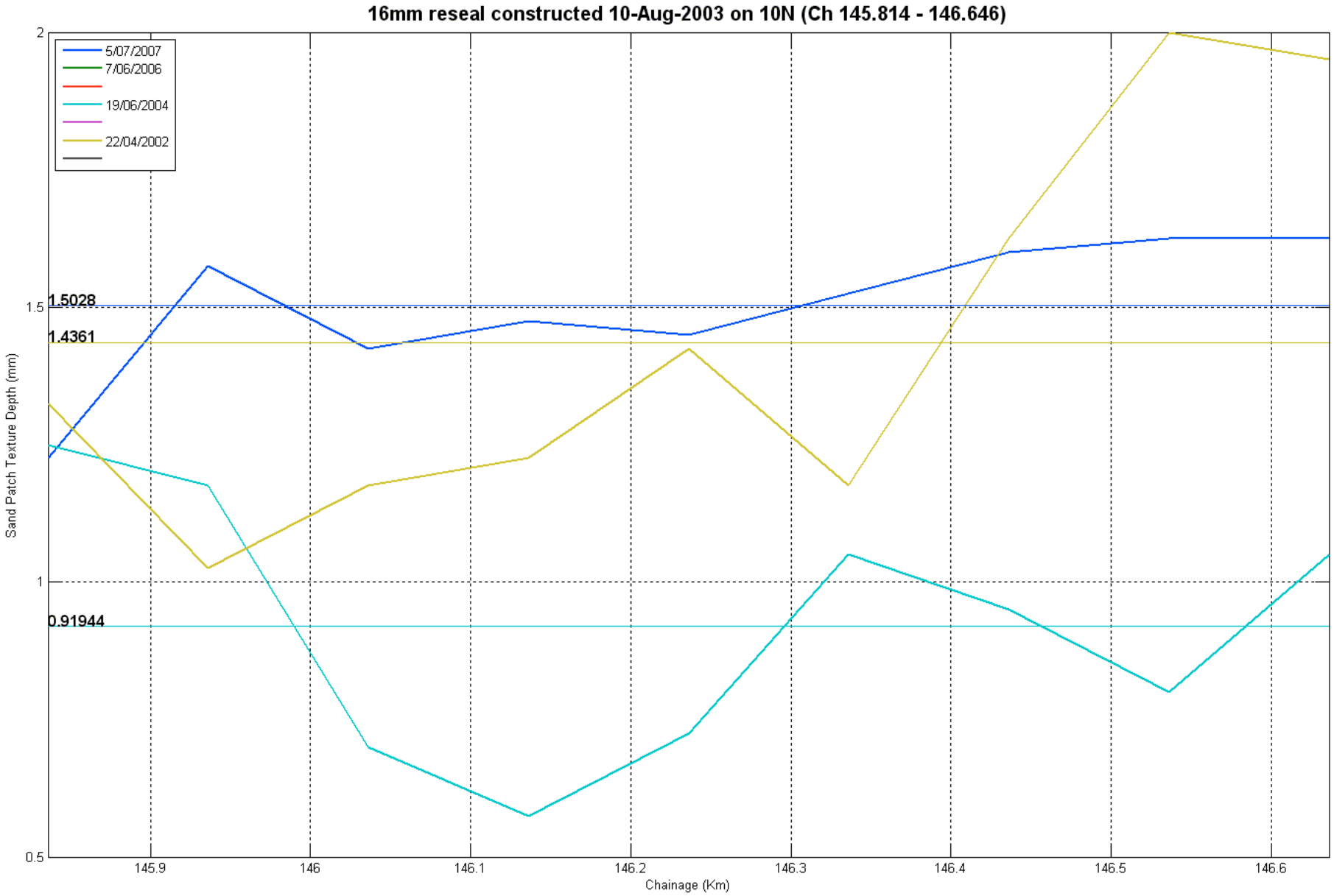

10mm reseal constructed 27-Sep-2001 on 92B (Ch 74.38 - 81.18)
20/11/2006
8/06/2005
12/06/2004
30/03/2003
10/04/2002
4/04/2001
2.8851
2.7087
2.4322
2.2312
1.8859
1.6112
Sand Patch Texture Depth (mm)
Chainage (Km)
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
75
76
77
78
79
80
81

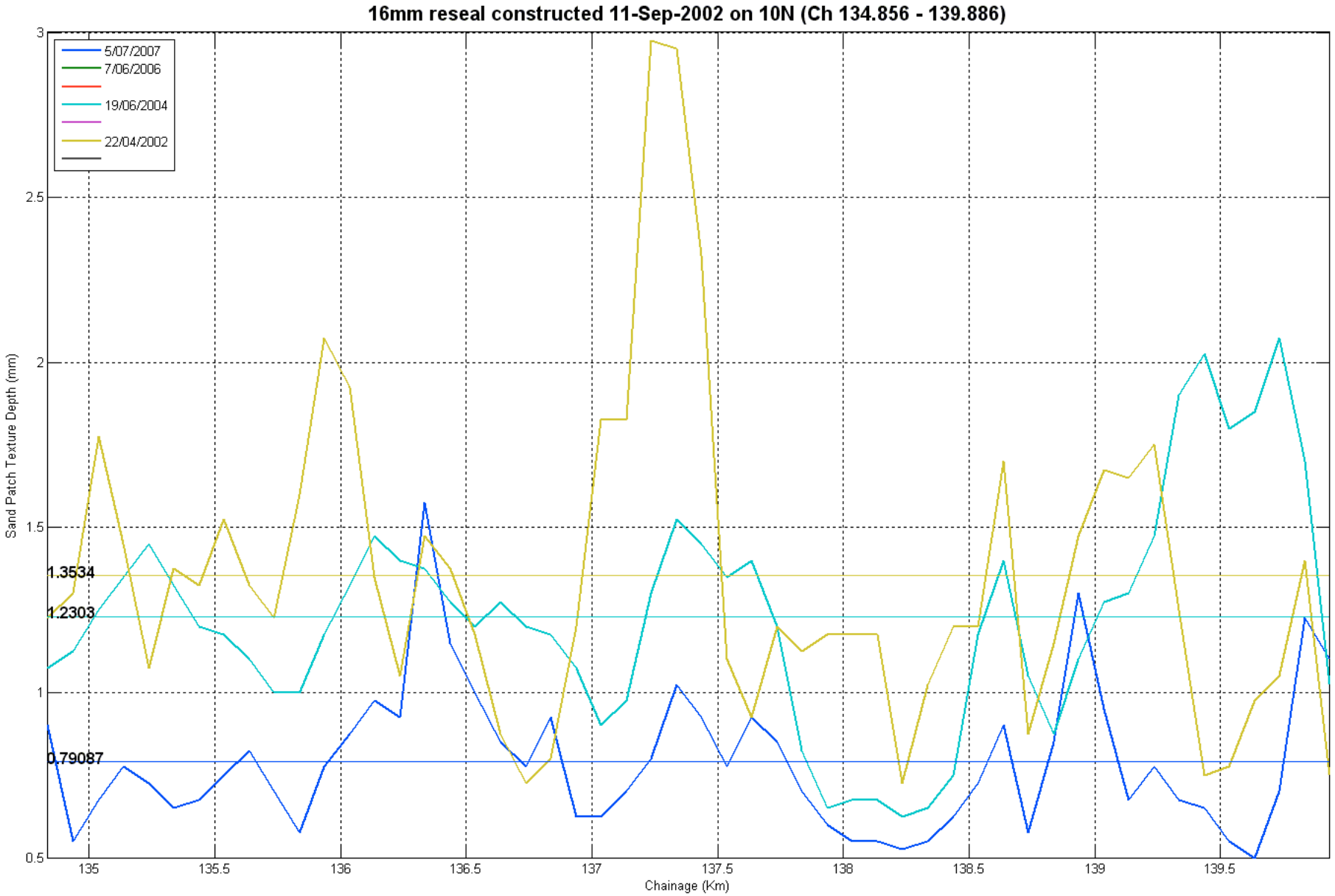

16mm reseal constructed 27-Sep-2002 on 92B (Ch 74.38 - 75.18)
20/11/2006
8/06/2005
12/06/2004
30/03/2003
10/04/2002
4/04/2001
2.975
2.7389
2.625
2.2167
2.1944
1.7722
Sand Patch Texture Depth (mm)
Chainage (Km)
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
74.4
74.5
74.6
74.7
74.8
74.9
75
75.1

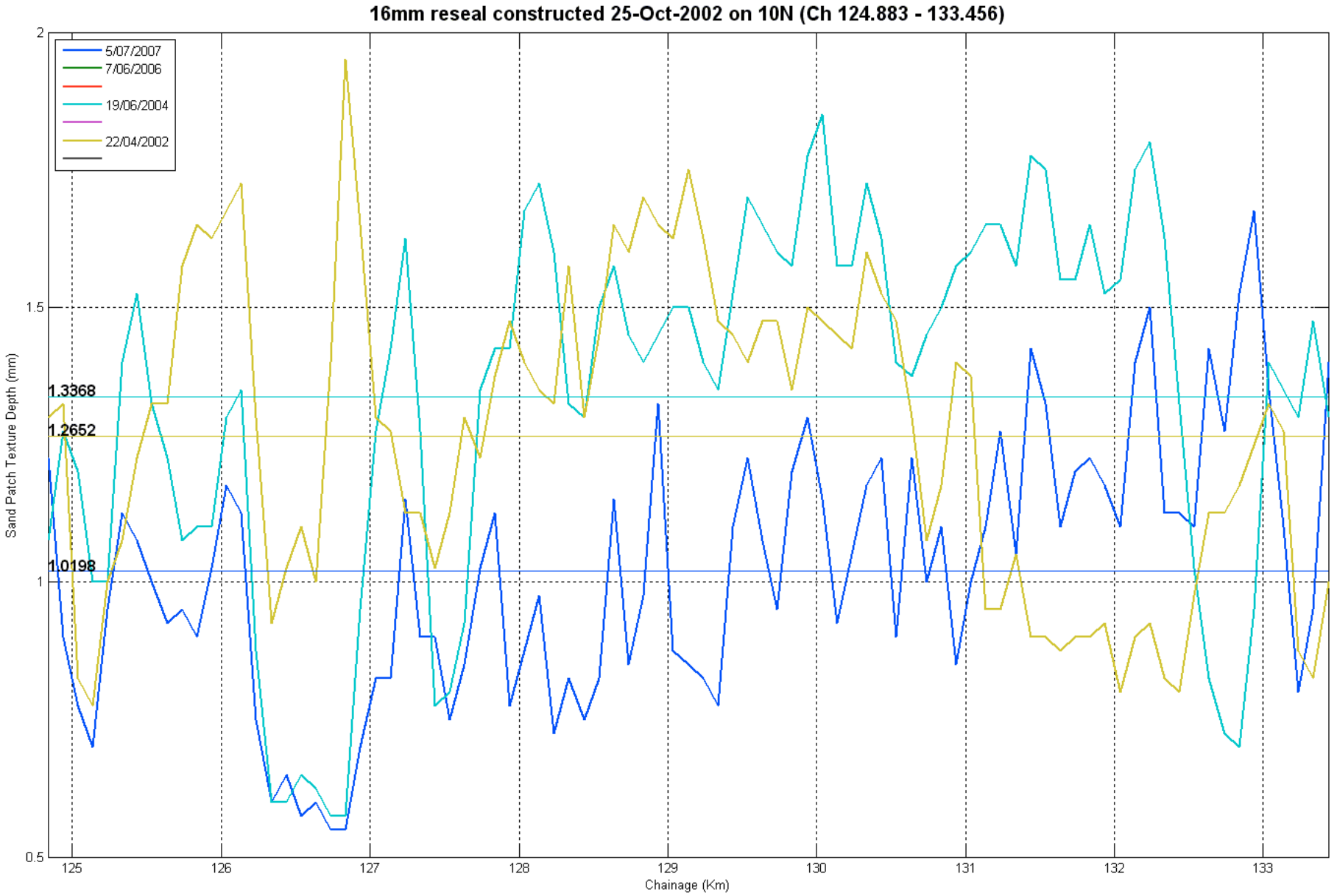

10mm reseal constructed 30-Oct-2000 on 92B (Ch 29.74 - 29.89)
20/11/2006
8/06/2005
12/06/2004
30/03/2003
10/04/2002
4/04/2001
2.475
2.4375
2.225
2.075
1.7625
1.6125
Sand Patch Texture Depth (mm)
Chainage (Km)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
29.75
29.76
29.77
29.78
29.79
29.8
29.81
29.82
29.83
29.84
29.85

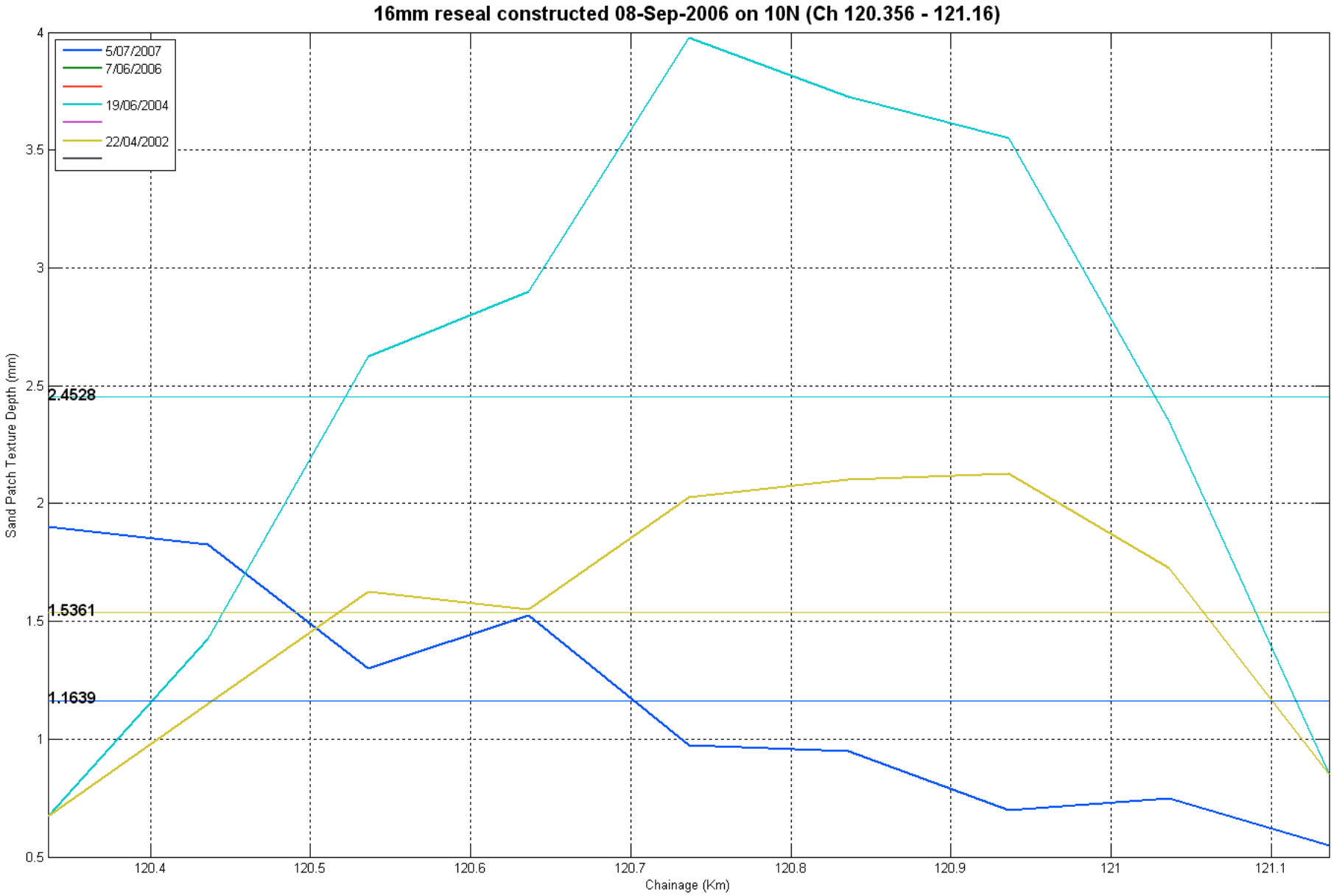

10mm reseal constructed 04-Jul-2003 on 92B (Ch 28.04 - 29.74)
20/11/2006
8/06/2005
12/06/2004
30/03/2003
10/04/2002
4/04/2001
2.5028
2.4111
2.0833
2.0292
1.825
1.7764
Sand Patch Texture Depth (mm)
Chainage (Km)
3.5
3
2.5
2
1.5
1
28.2
28.4
28.6
28.8
29
29.2
29.4
29.6

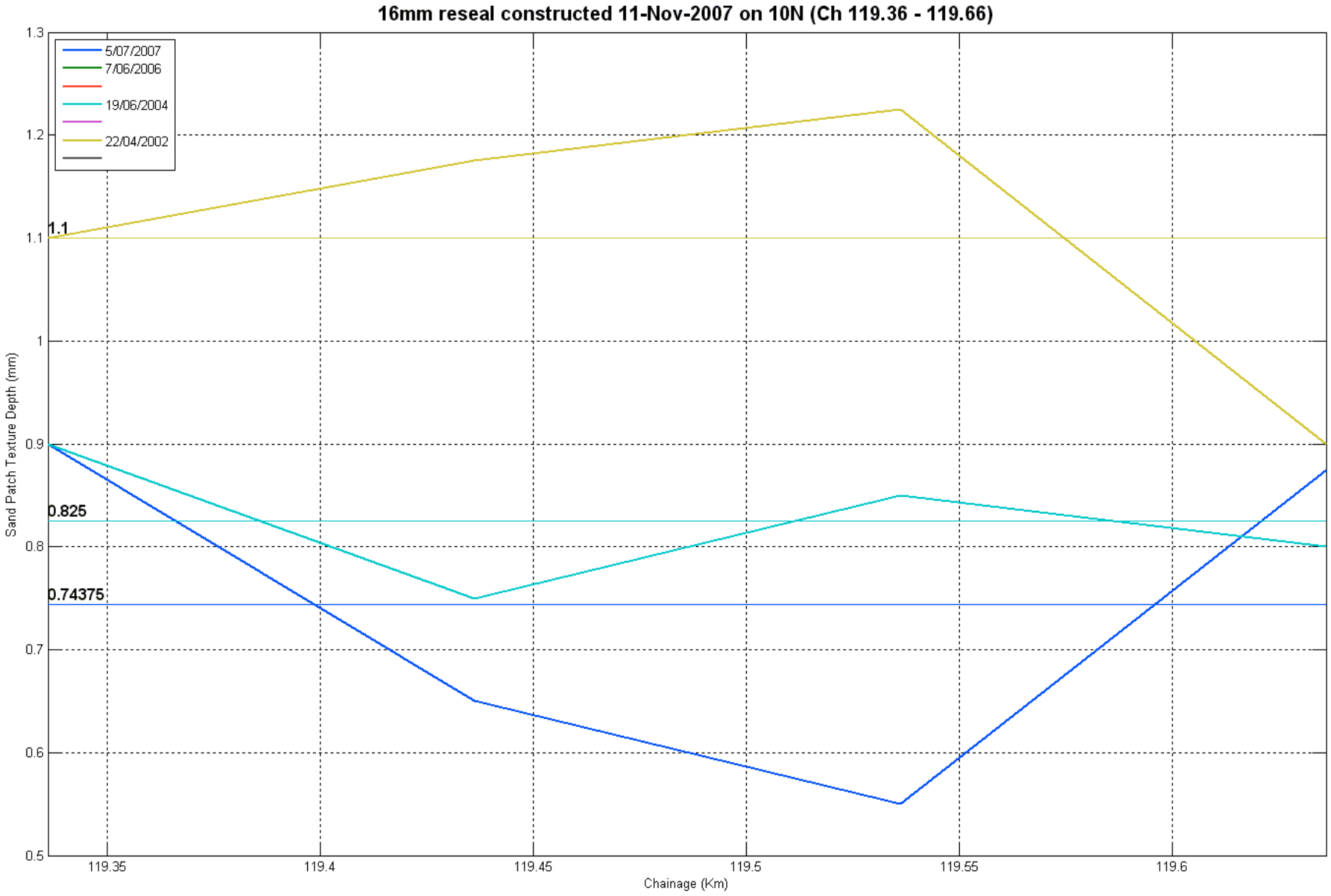

10mm reseal constructed 22-Oct-2004 on 92B (Ch 28.07 - 28.12)
20/11/2006
8/06/2005
12/06/2004
30/03/2003
10/04/2002
4/04/2001
2.3625
2.275
2.2375
2.075
2.025
1.5625
Sand Patch Texture Depth (mm)
Chainage (Km)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
28.05
28.06
28.07
28.08
28.09
28.1
28.11
28.12
28.13
28.14
28.15

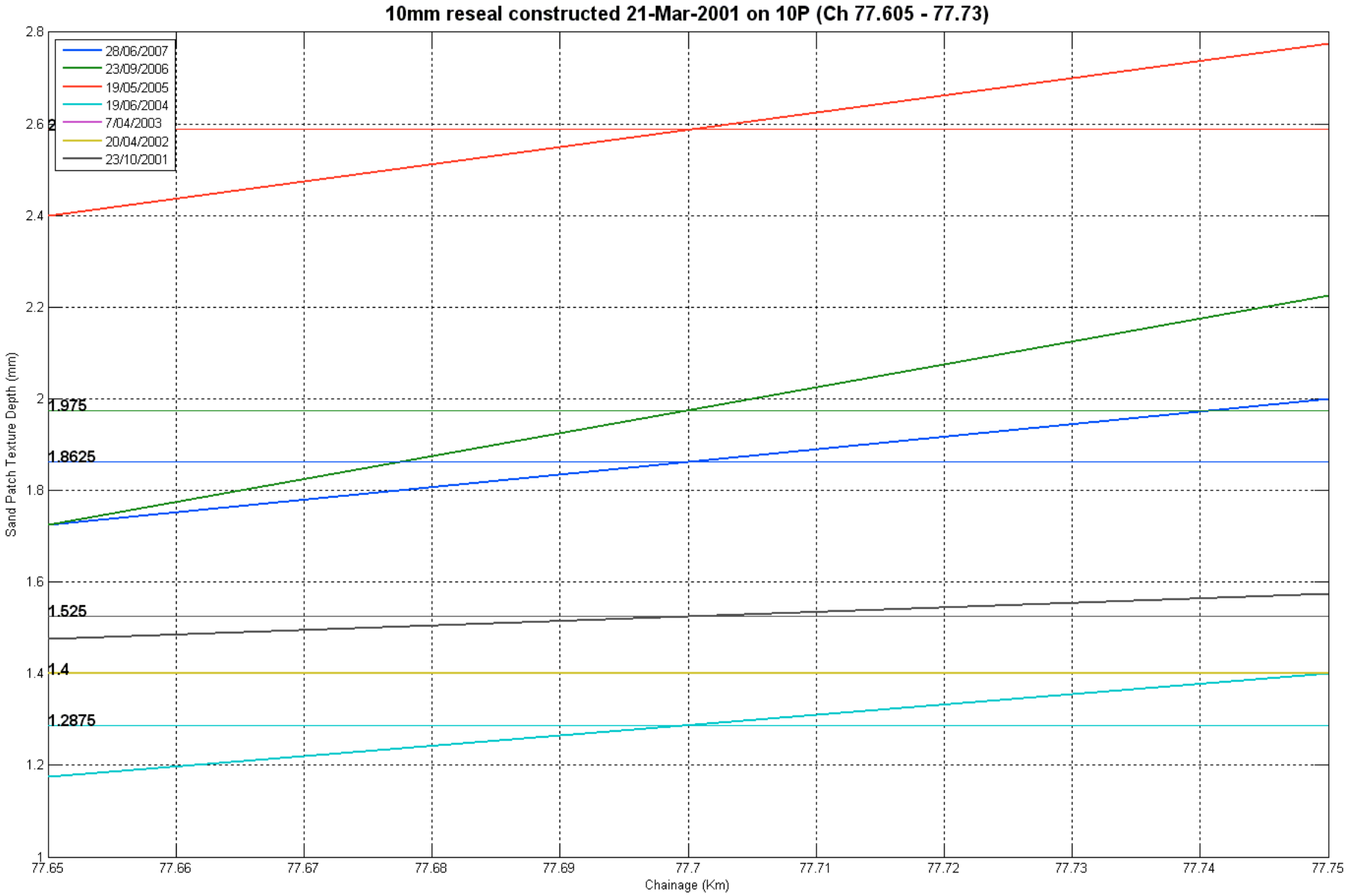

16mm reseal constructed 10-Aug-2003 on 10N (Ch 145.814 - 146.646)
5/07/2007
7/06/2006
19/06/2004
22/04/2002
1.5028
1.4361
0.91944
Sand Patch Texture Depth (mm)
Chainage (Km)
2
1.5
1
0.5
145.9
146
146.1
146.2
146.3
146.4
146.5
146.6

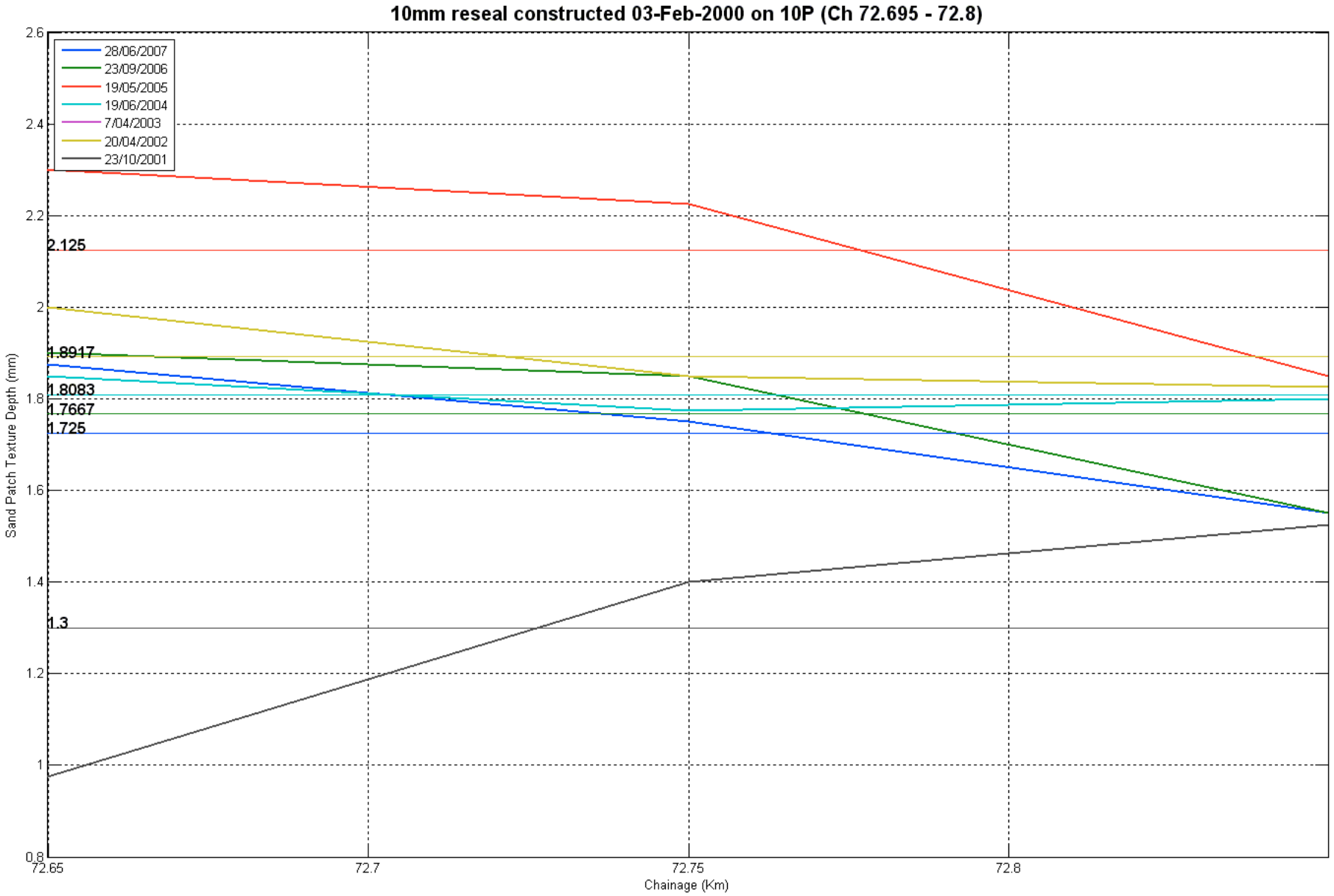

16mm reseal constructed 11-Sep-2002 on 10N (Ch 134.856 - 139.886)
5/07/2007
7/06/2006
19/06/2004
22/04/2002
Sand Patch Texture Depth (mm)
Chainage (Km)
1.3534
1.2303
0.79087
3
2.5
2
1.5
1
0.5
135
135.5
136
136.5
137
137.5
138
138.5
139
139.5

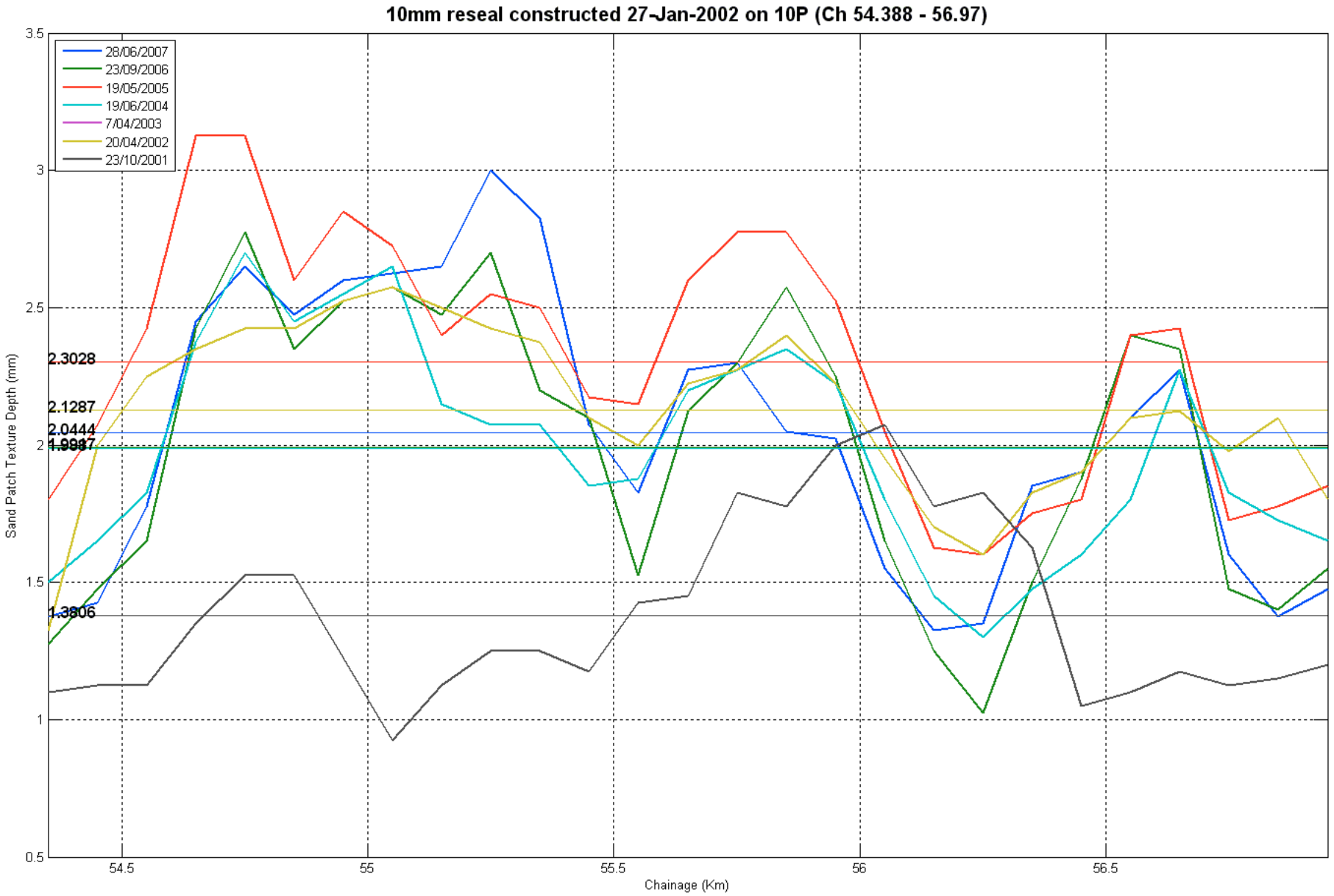

16mm reseal constructed 25-Oct-2002 on 10N (Ch 124.883 - 133.456)
5/07/2007
7/06/2006
19/06/2004
22/04/2002
1.3368
1.2652
1.0198
Sand Patch Texture Depth (mm)
Chainage (Km)
2
1.5
1
0.5
125
126
127
128
129
130
131
132
133

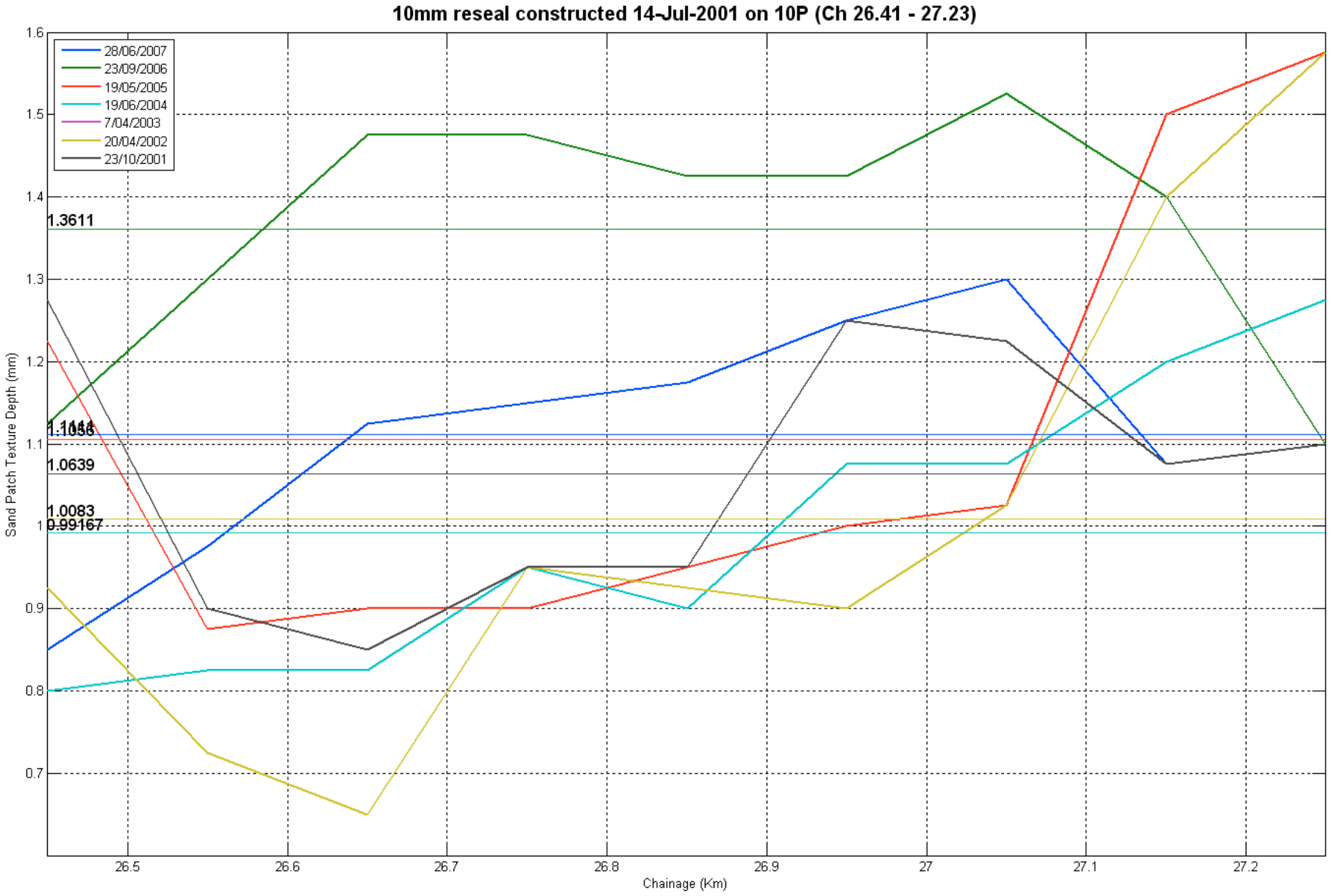

16mm reseal constructed 08-Sep-2006 on 10N (Ch 120.356 - 121.16)
5/07/2007
7/06/2006
19/06/2004
22/04/2002
2.4528
1.5361
1.1639
Sand Patch Texture Depth (mm)
Chainage (Km)
4
3.5
3
2.5
2
1.5
1
0.5
120.4
120.5
120.6
120.7
120.8
120.9
121
121.1

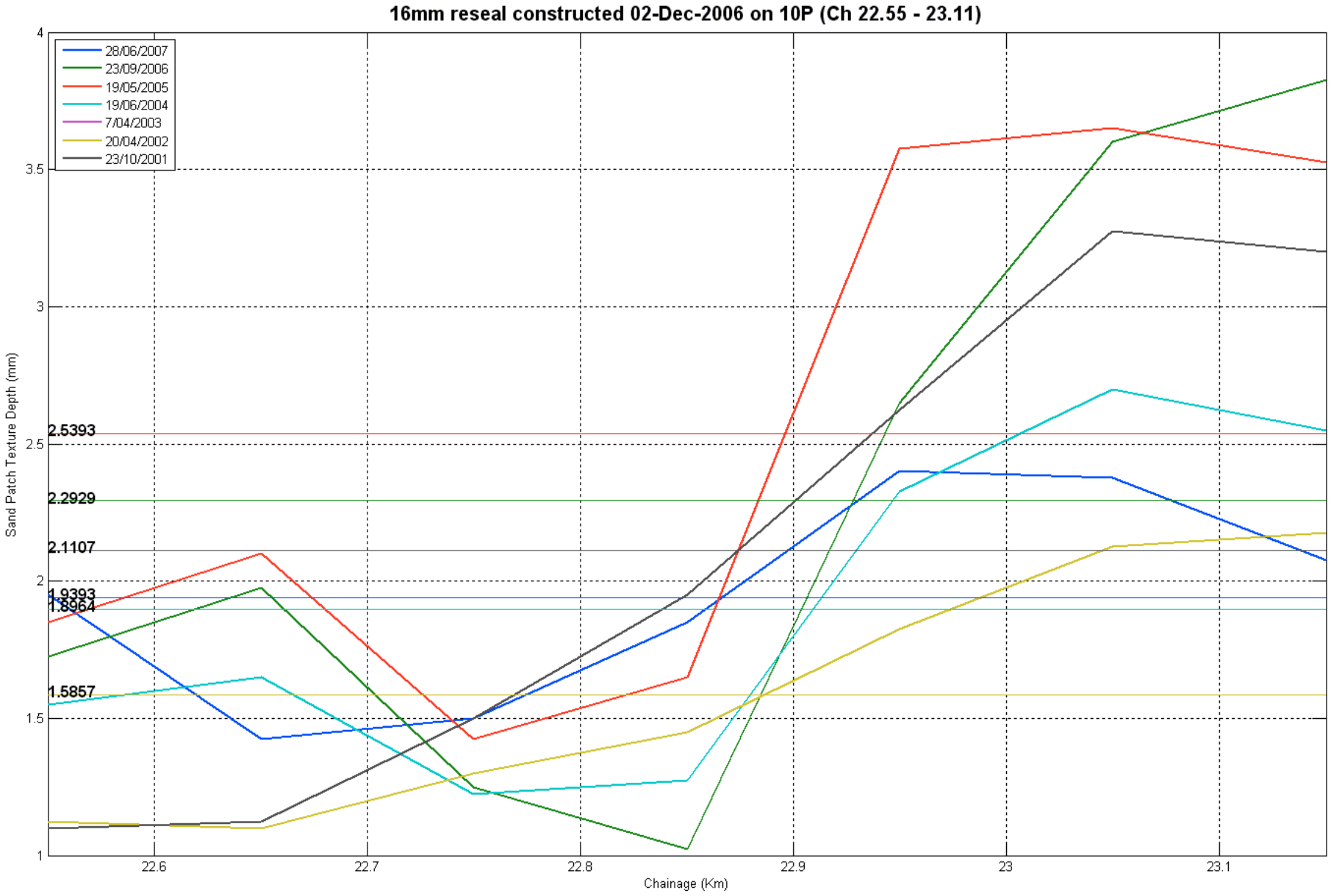

16mm reseal constructed 11-Nov-2007 on 10N (Ch 119.36 - 119.66)
5/07/2007
7/06/2006
19/06/2004
22/04/2002
1.1
0.825
0.74375
Sand Patch Texture Depth (mm)
Chainage (Km)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
119.35
119.4
119.45
119.5
119.55
119.6

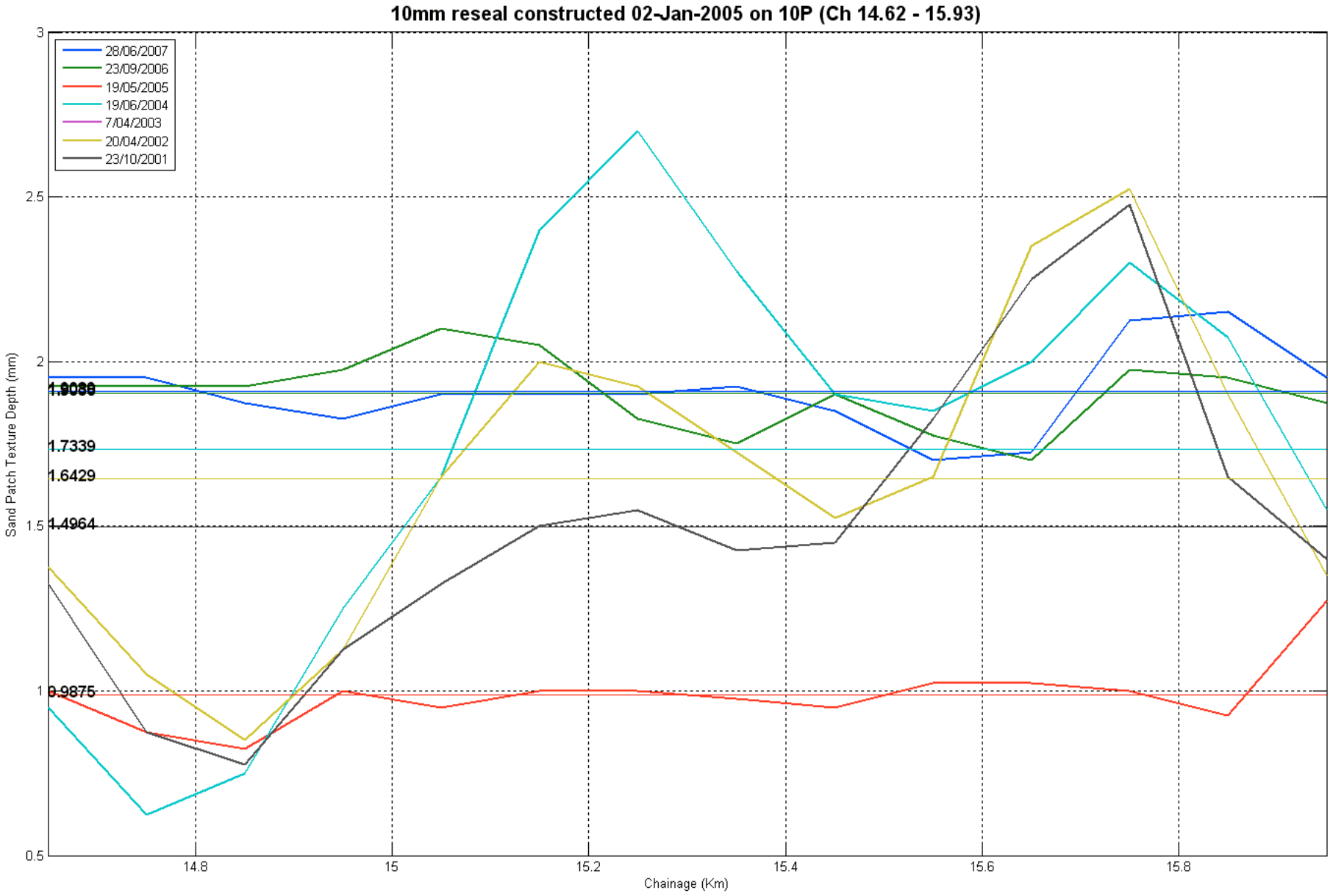

10mm reseal constructed 21-Mar-2001 on 10P (Ch 77.605 - 77.73)
28/06/2007
23/09/2006
19/05/2005
19/06/2004
7/04/2003
20/04/2002
23/10/2001
2
1.975
1.8625
1.525
1.4
1.2875
Sand Patch Texture Depth (mm)
Chainage (Km)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
77.65
77.66
77.67
77.68
77.69
77.7
77.71
77.72
77.73
77.74
77.75

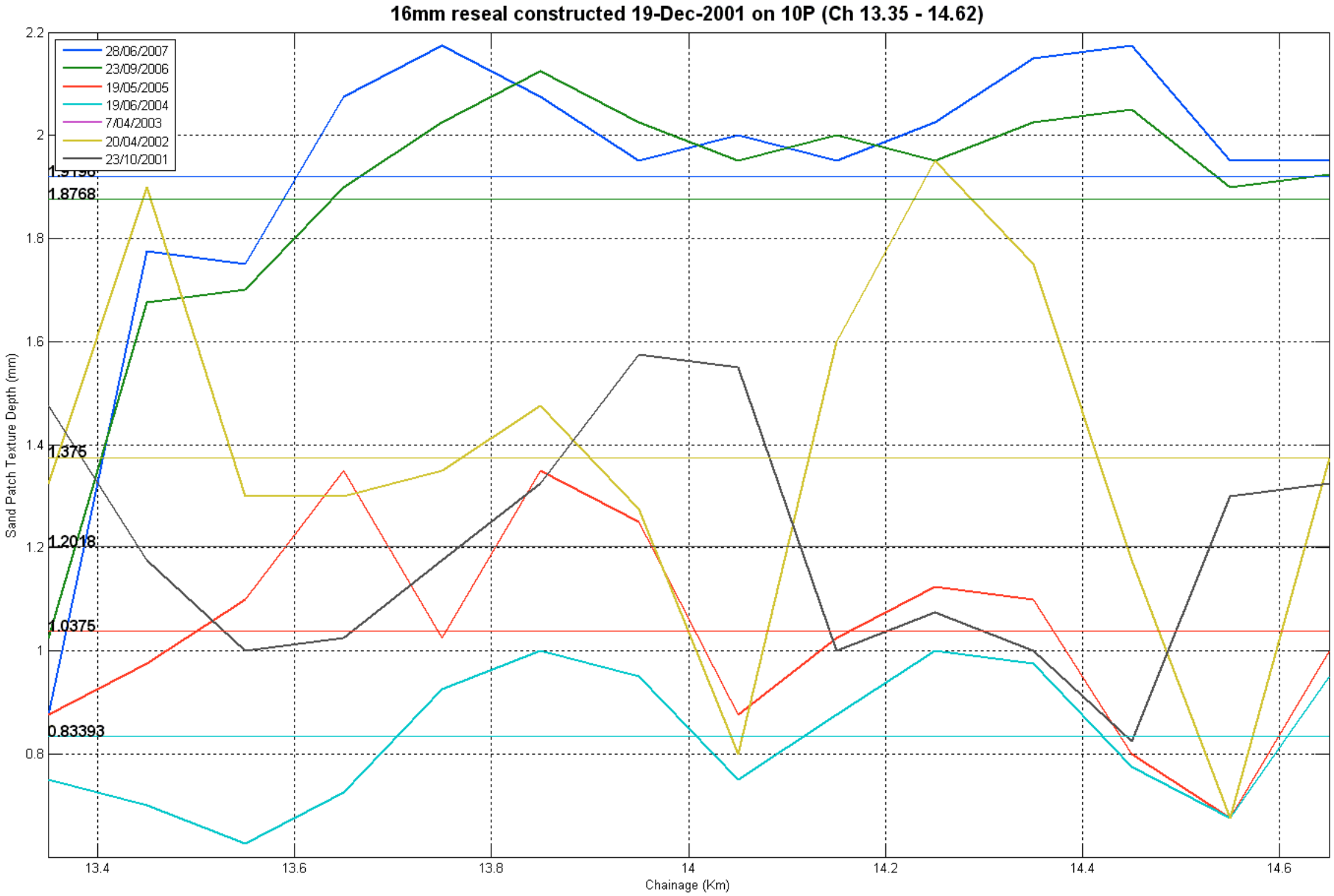

10mm reseal constructed 03-Feb-2000 on 10P (Ch 72.695 - 72.8)
28/06/2007
23/09/2006
19/05/2005
19/06/2004
7/04/2003
20/04/2002
23/10/2001
2.125
1.8917
1.8083
1.7667
1.725
1.3
Sand Patch Texture Depth (mm)
Chainage (Km)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
72.65
72.7
72.75
72.8

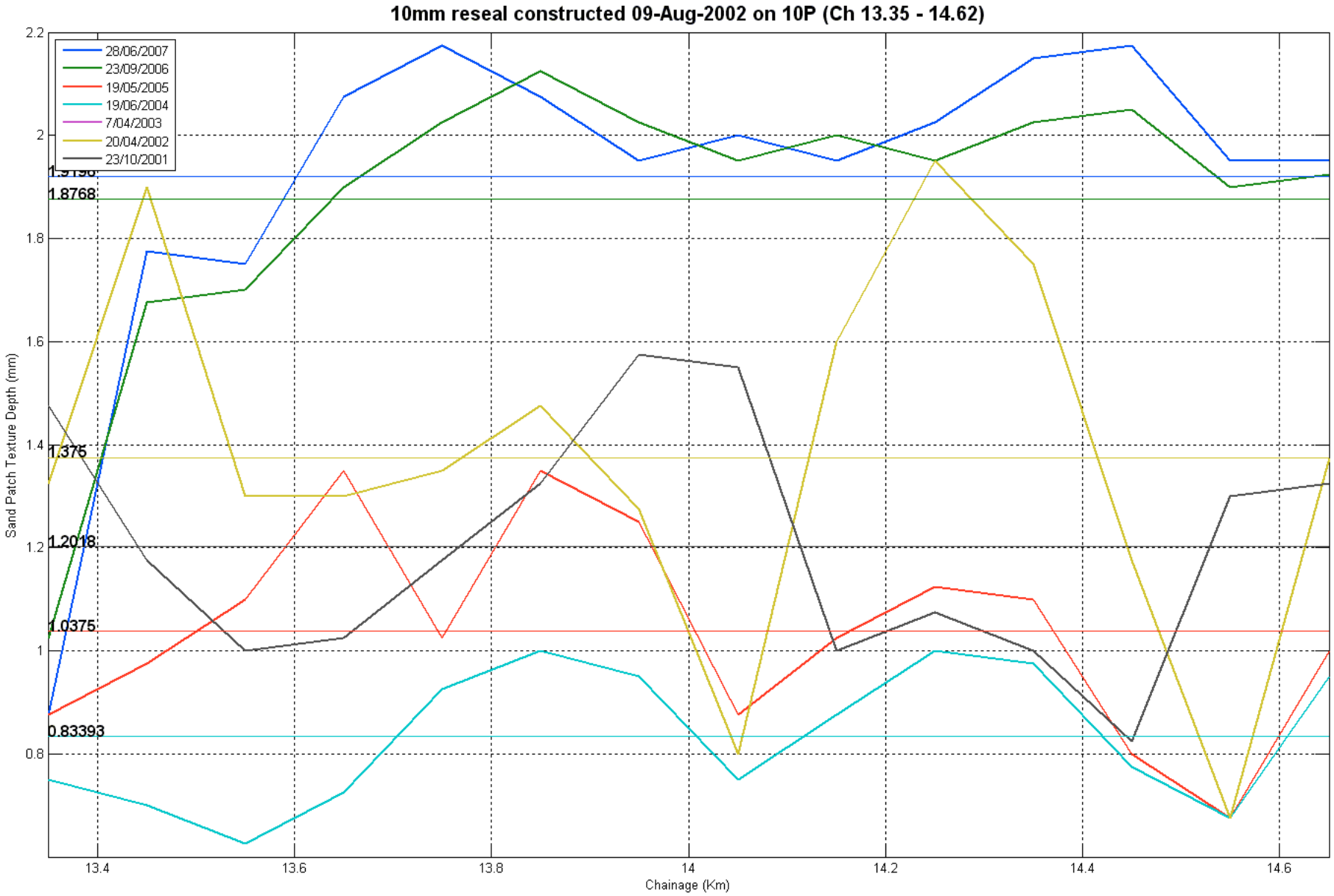

10mm reseal constructed 27-Jan-2002 on 10P (Ch 54.388 - 56.97)
28/06/2007
23/09/2006
19/05/2005
19/06/2004
7/04/2003
20/04/2002
23/10/2001
2.3028
2.1287
2.0444
1.9987
1.3806
Sand Patch Texture Depth (mm)
Chainage (Km)
3.5
3
2.5
2
1.5
1
0.5
54.5
55
55.5
56
56.5


10mm reseal constructed 14-Jul-2001 on 10P (Ch 26.41 - 27.23)
28/06/2007
23/09/2006
19/05/2005
19/06/2004
7/04/2003
20/04/2002
23/10/2001
1.3611
1.0639
1.0083
0.99167
Sand Patch Texture Depth (mm)
Chainage (Km)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
26.5
26.6
26.7
26.8
26.9
27
27.1
27.2

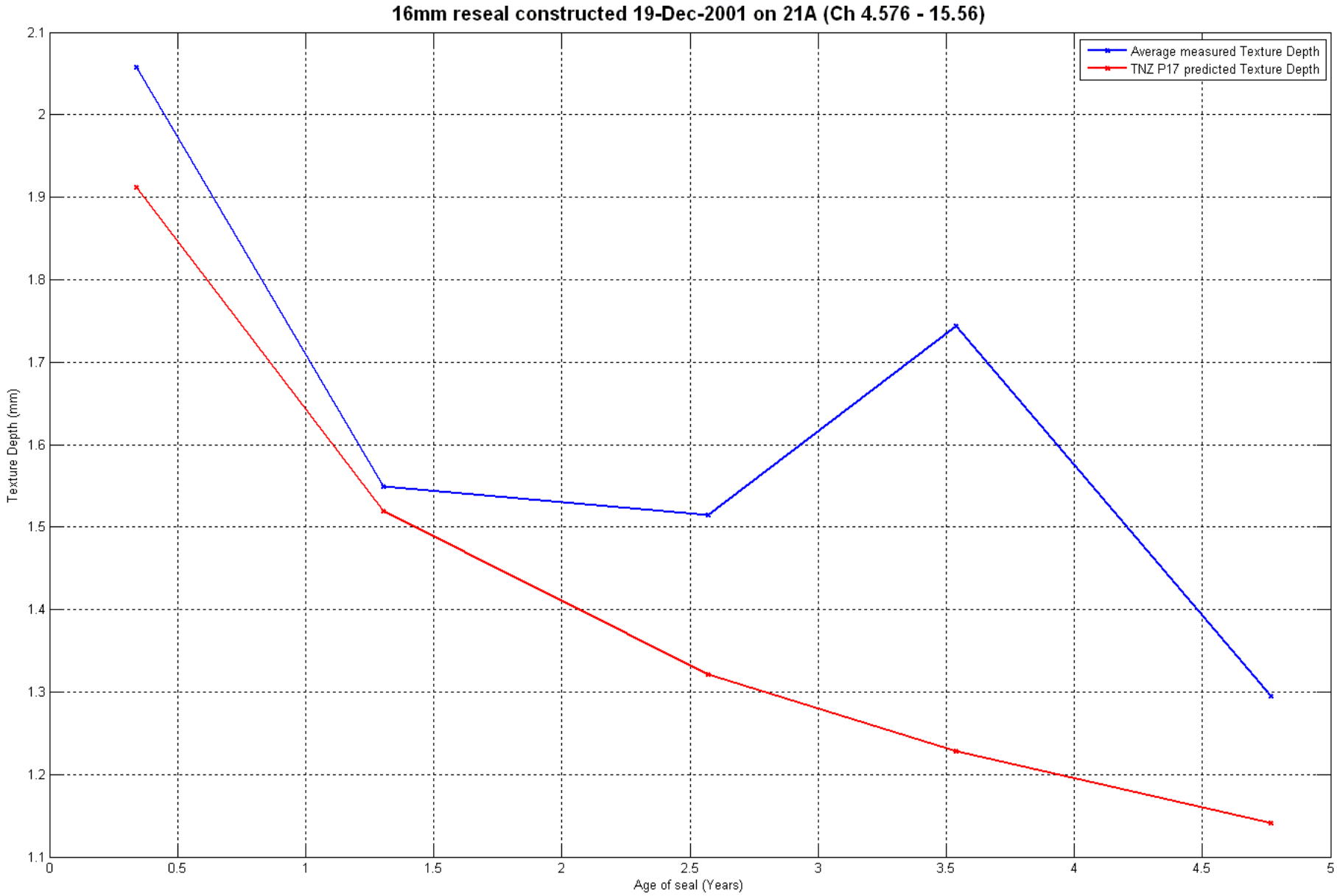

16mm reseal constructed 02-Dec-2006 on 10P (Ch 22.55 - 23.11)
28/06/2007
23/09/2006
19/05/2005
19/06/2004
7/04/2003
20/04/2002
23/10/2001
Sand Patch Texture Depth (mm)
Chainage (Km)
4
3.5
3
2.5
2
1.5
1
22.6
22.7
22.8
22.9
23
23.1
2.5393
2.2929
2.1107
1.9393
1.8964
1.5857

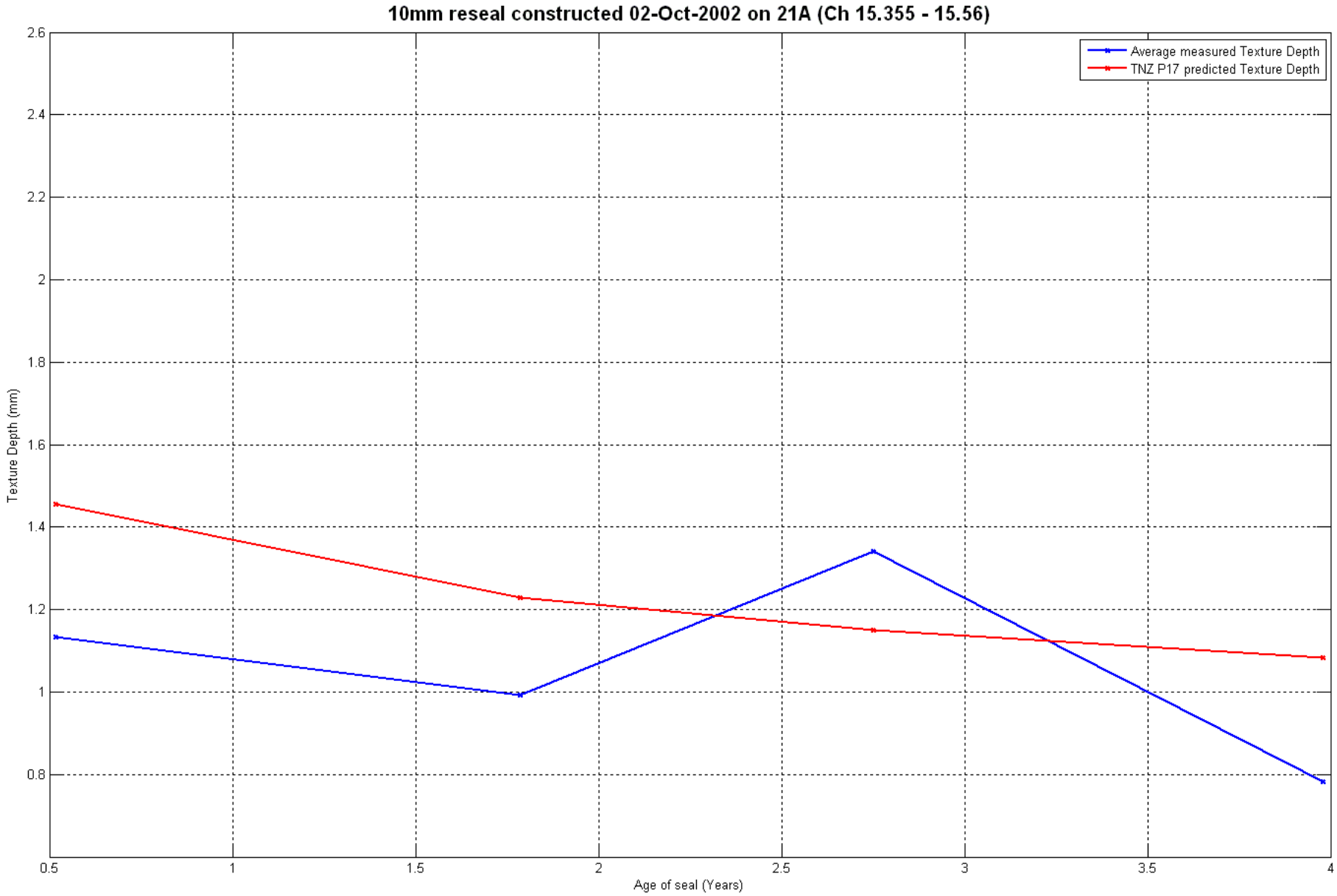

10mm reseal constructed 02-Jan-2005 on 10P (Ch 14.62 - 15.93)
28/06/2007
23/09/2006
19/05/2005
19/06/2004
7/04/2003
20/04/2002
23/10/2001
Sand Patch Texture Depth (mm)
Chainage (Km)
3
2.5
2
1.5
1
0.5
1.9088
1.7339
1.6429
1.4964
0.9875
14.8
15
15.2
15.4
15.6
15.8

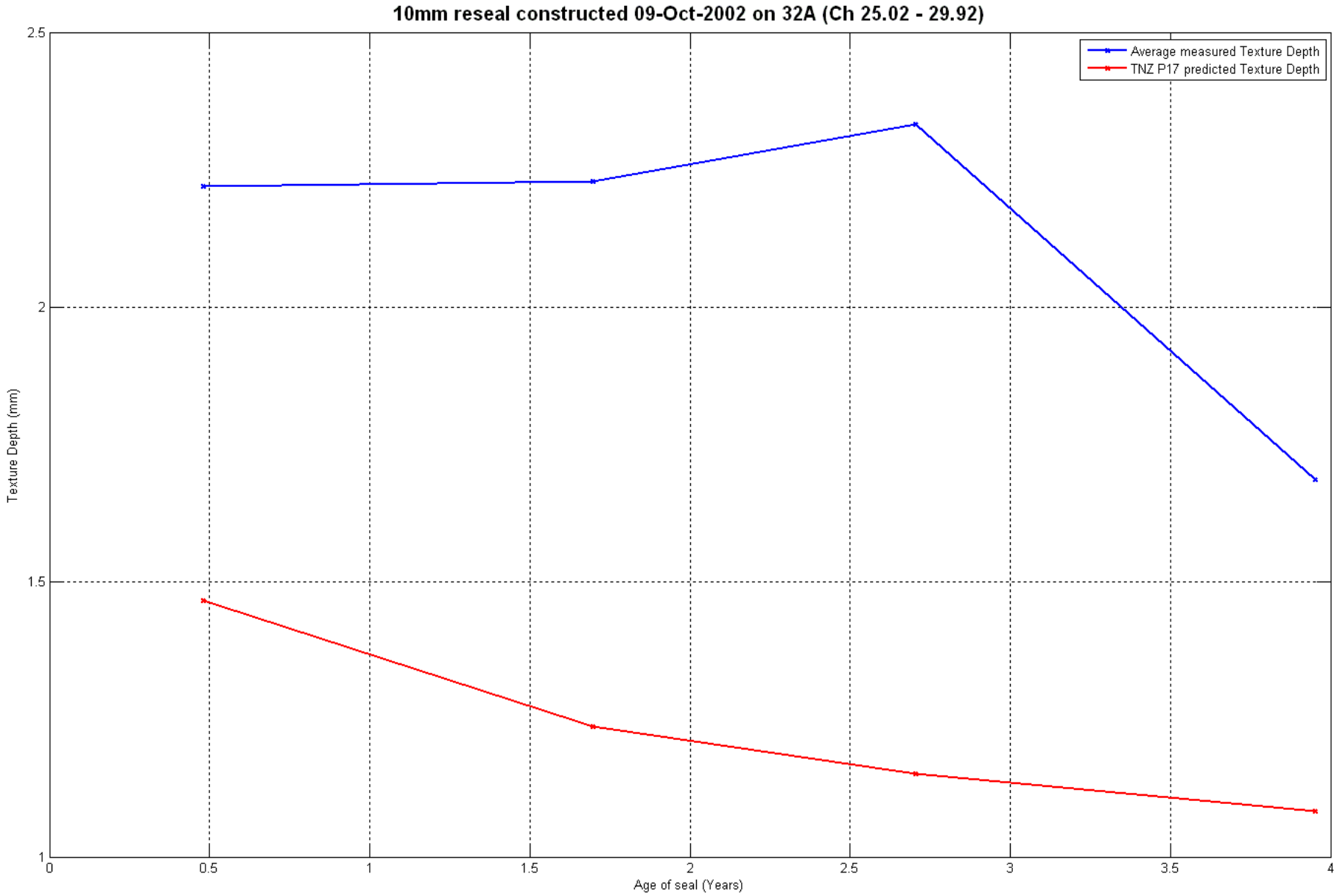

16mm reseal constructed 19-Dec-2001 on 10P (Ch 13.35 - 14.62)
28/06/2007
23/09/2006
19/05/2005
19/06/2004
7/04/2003
20/04/2002
23/10/2001
1.8768
1.375
1.2018
1.0375
0.83393
Sand Patch Texture Depth (mm)
Chainage (Km)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
13.4
13.6
13.8
14
14.2
14.4
14.6

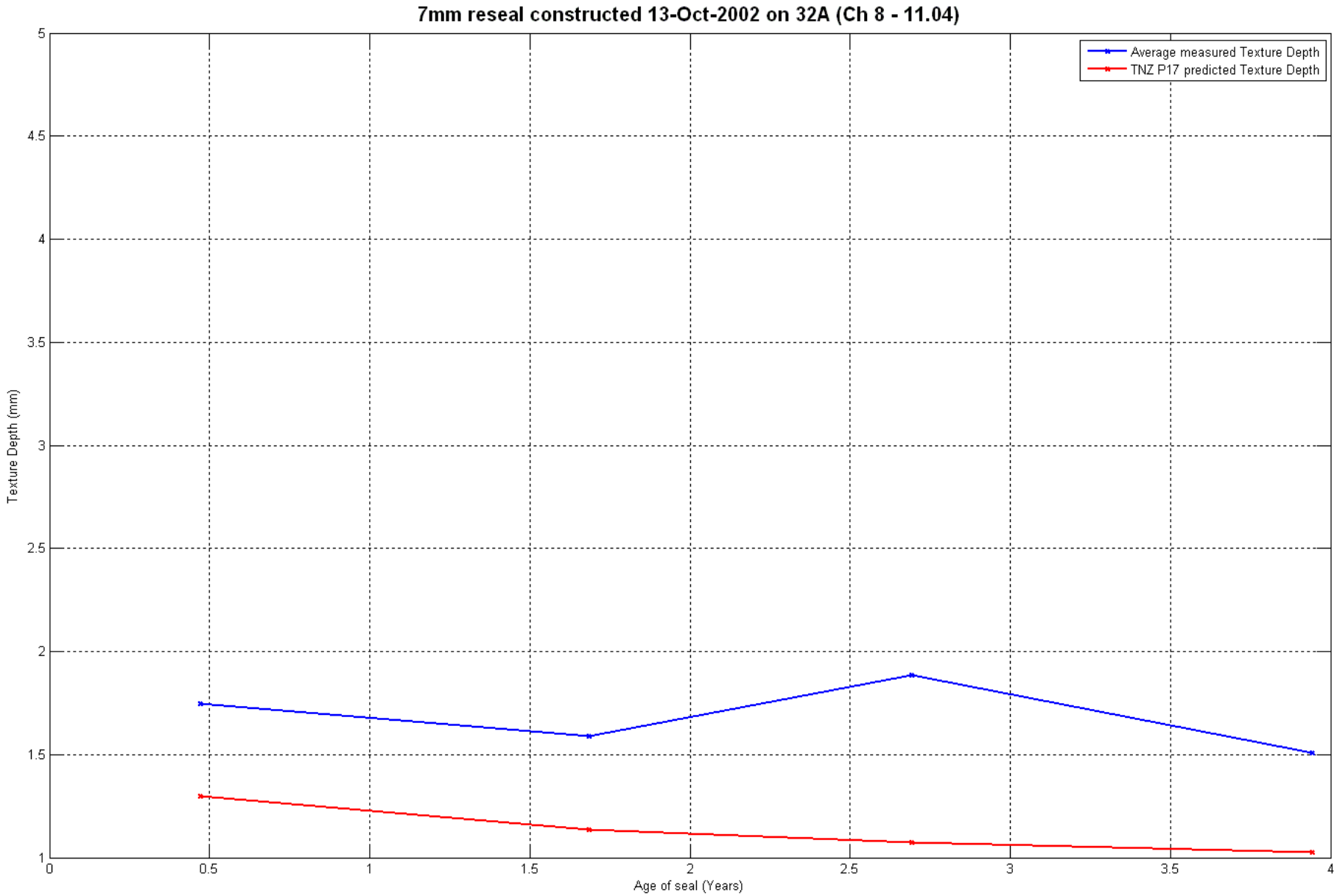

10mm reseal constructed 09-Aug-2002 on 10P (Ch 13.35 - 14.62)
28/06/2007
23/09/2006
19/05/2005
19/06/2004
7/04/2003
20/04/2002
23/10/2001
1.8768
1.375
1.2018
1.0375
0.83393
Sand Patch Texture Depth (mm)
Chainage (Km)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
13.4
13.6
13.8
14
14.2
14.4
14.6

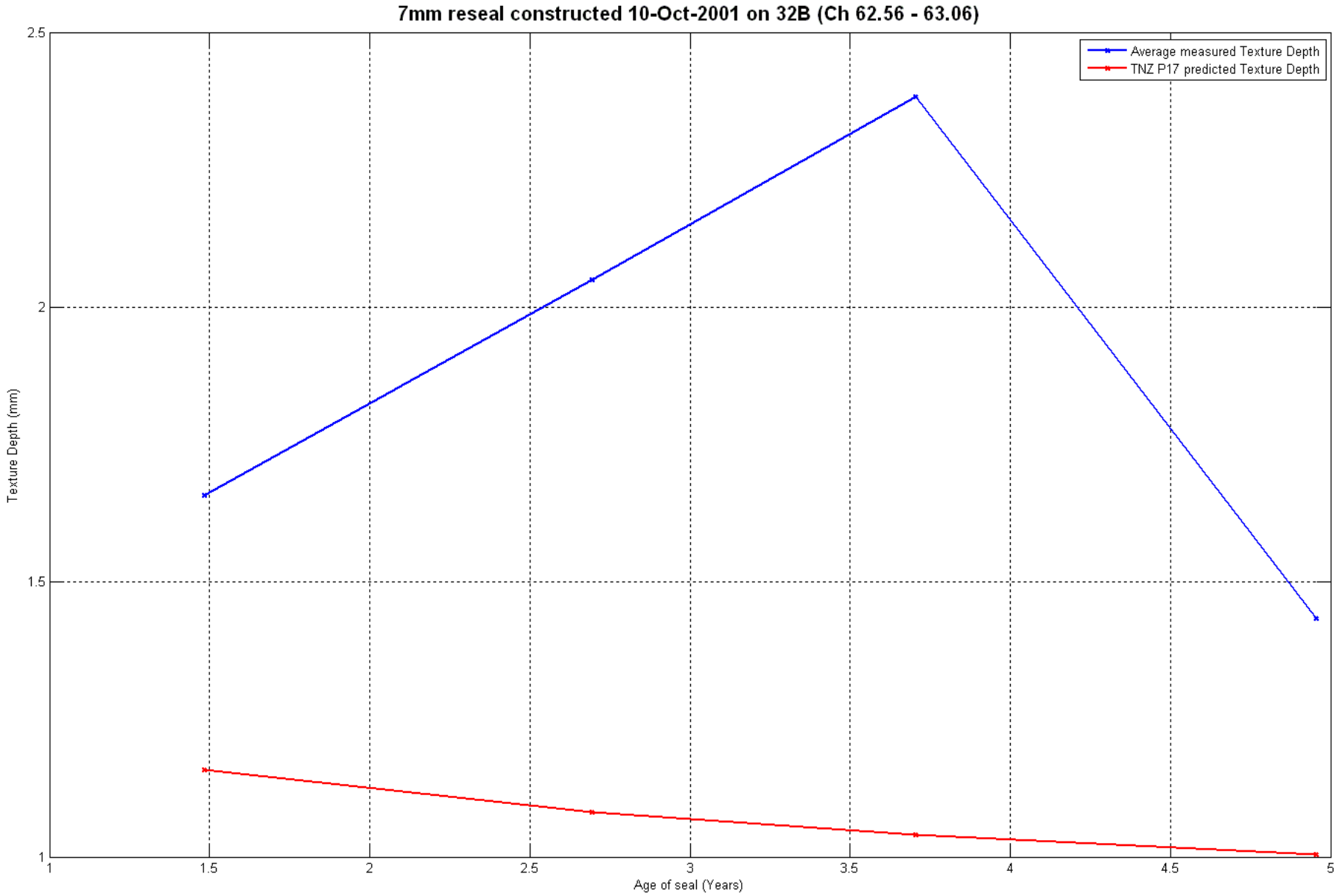
Appendix G texture depth deterioration charts

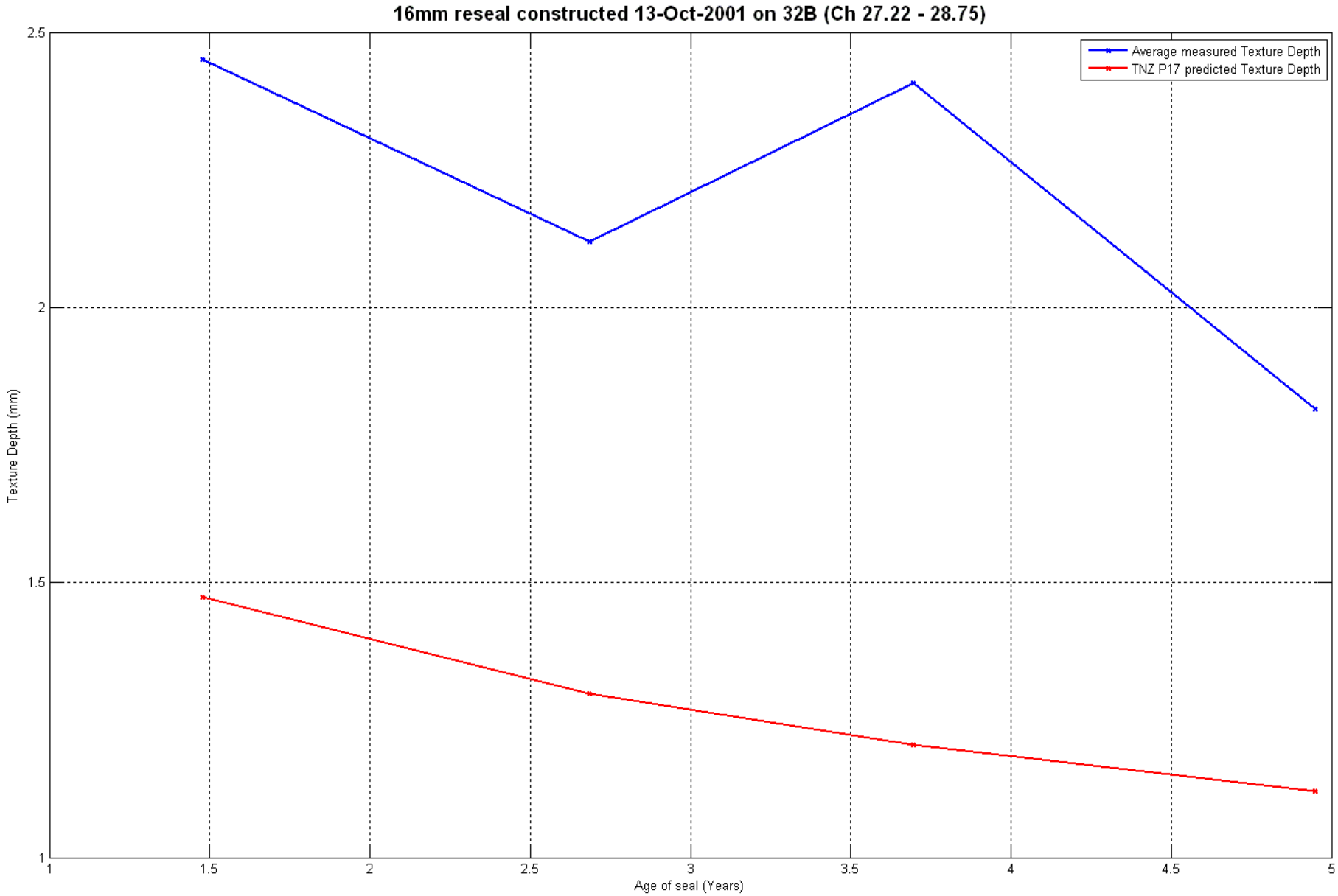

16mm reseal constructed 19-Dec-2001 on 21A (Ch 4.576 - 15.56)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

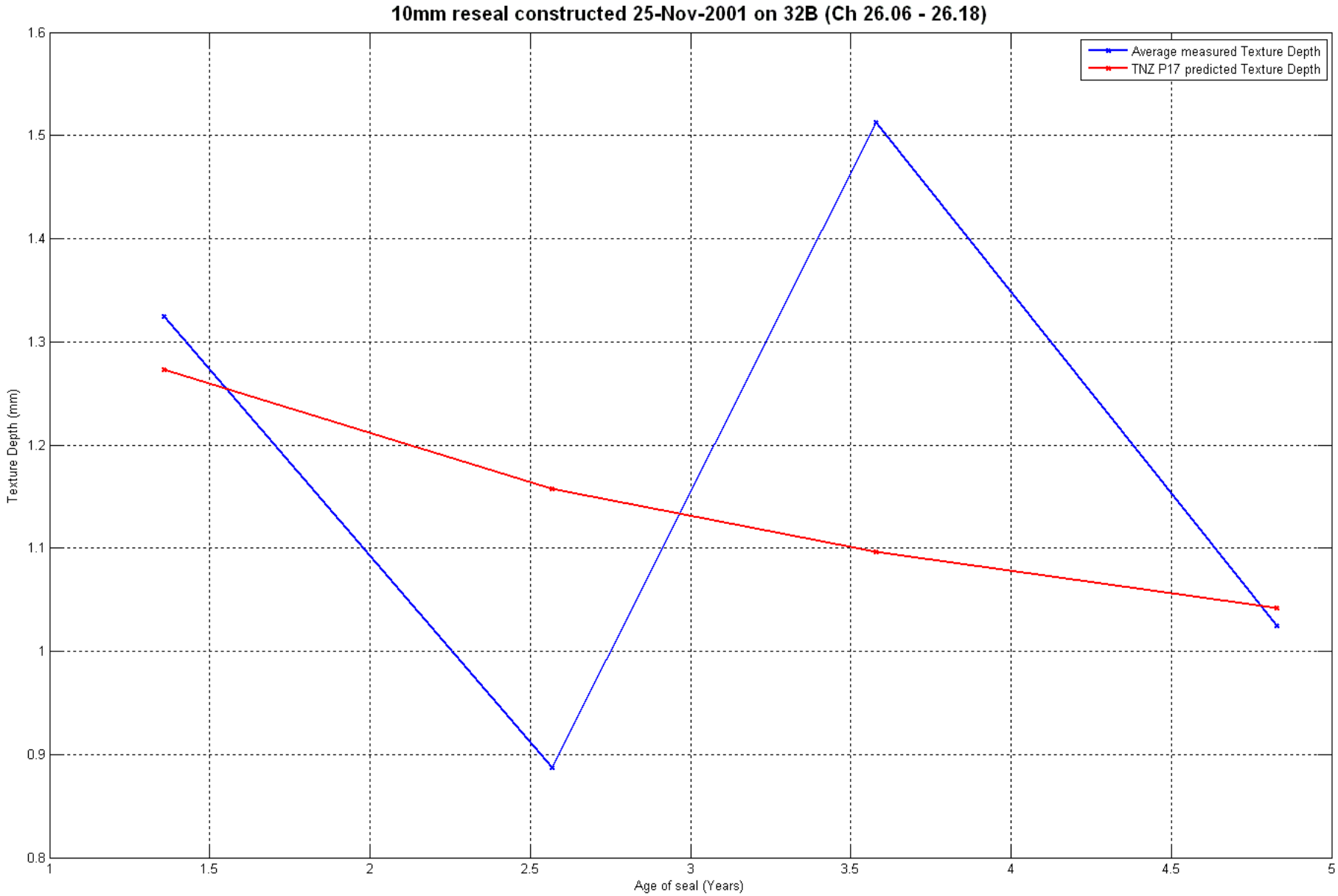

10mm reseal constructed 02-Oct-2002 on 21A (Ch 15.355 - 15.56)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.5
1
1.5
2
2.5
3
3.5
4

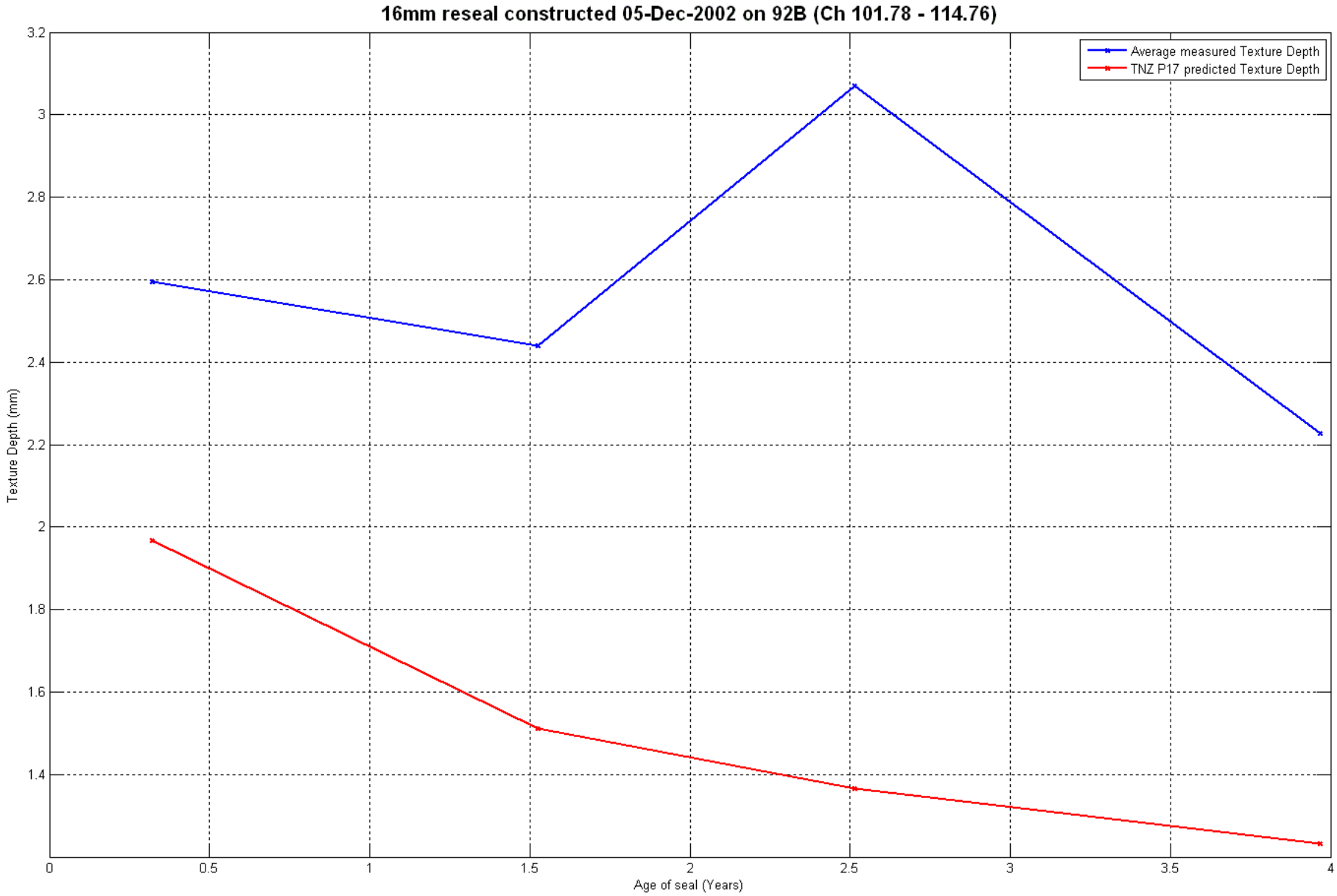

10mm reseal constructed 09-Oct-2002 on 32A (Ch 25.02 - 29.92)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.5
2
1.5
1
0
0.5
1
1.5
2
2.5
3
3.5
4

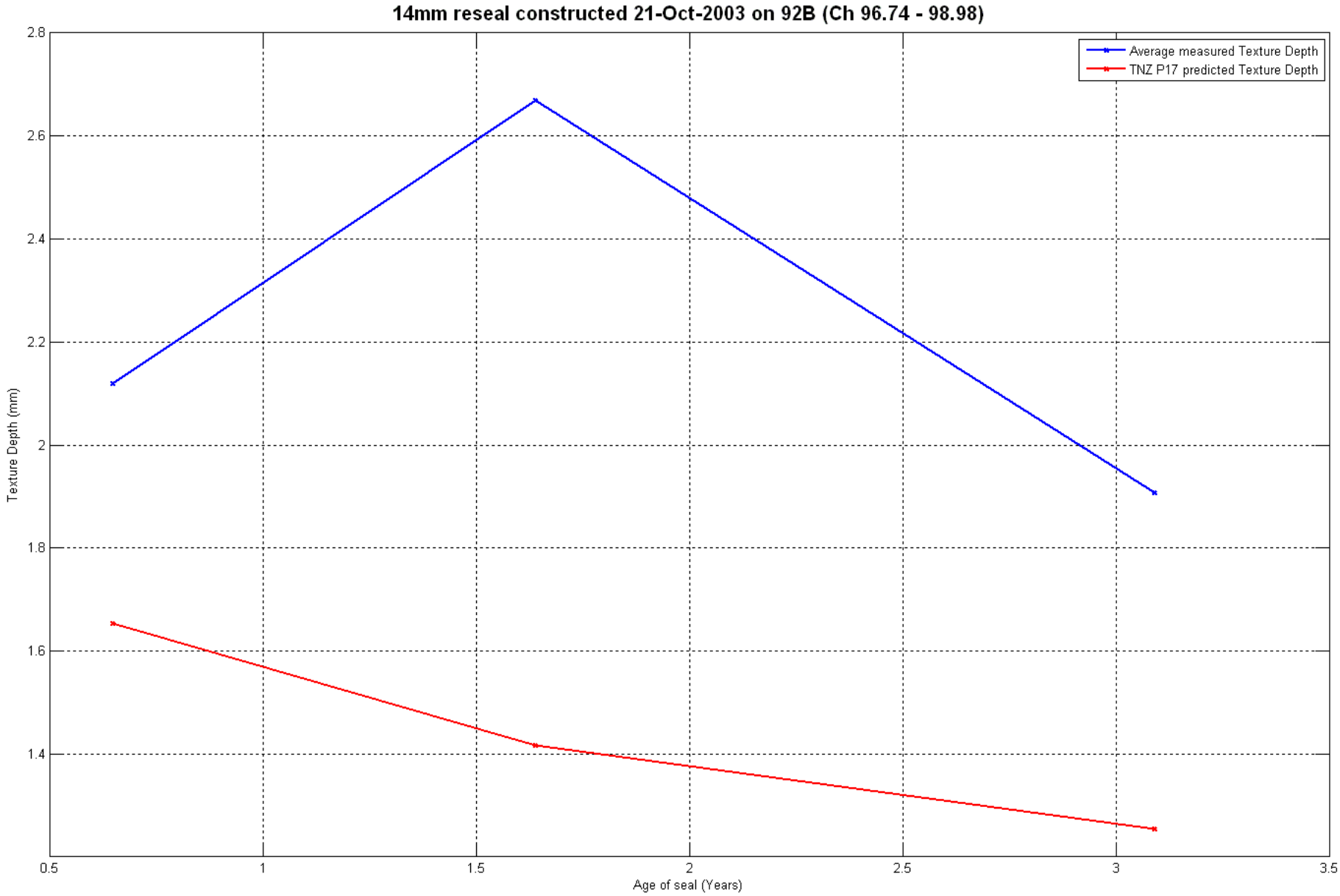

7mm reseal constructed 13-Oct-2002 on 32A (Ch 8 - 11.04)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
5
4.5
4
3.5
3
2.5
2
1.5
1
0
0.5
1
1.5
2
2.5
3
3.5
4

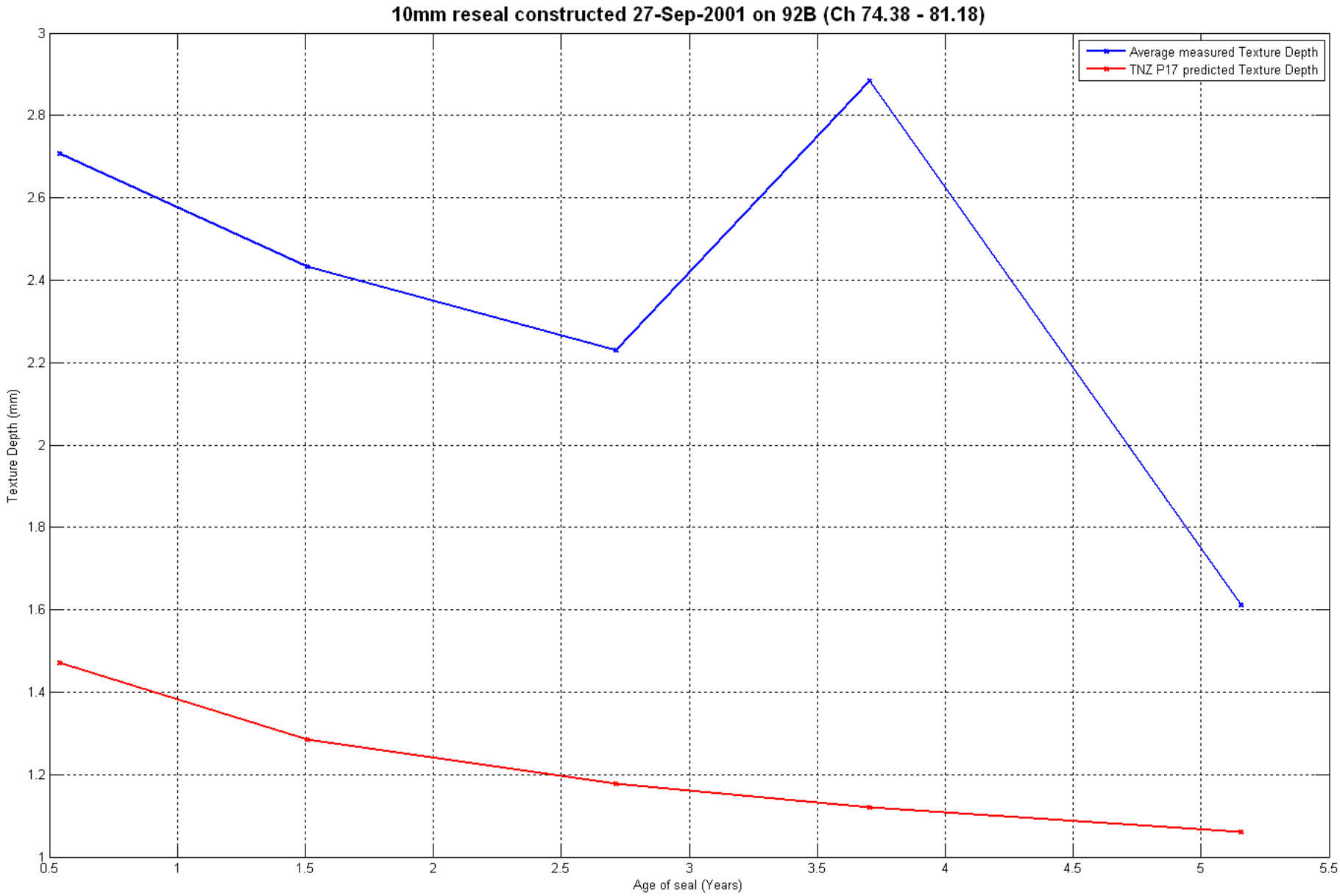

7mm reseal constructed 10-Oct-2001 on 32B (Ch 62.56 - 63.06)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.5
2
1.5
1
1
1.5
2
2.5
3
3.5
4
4.5
5

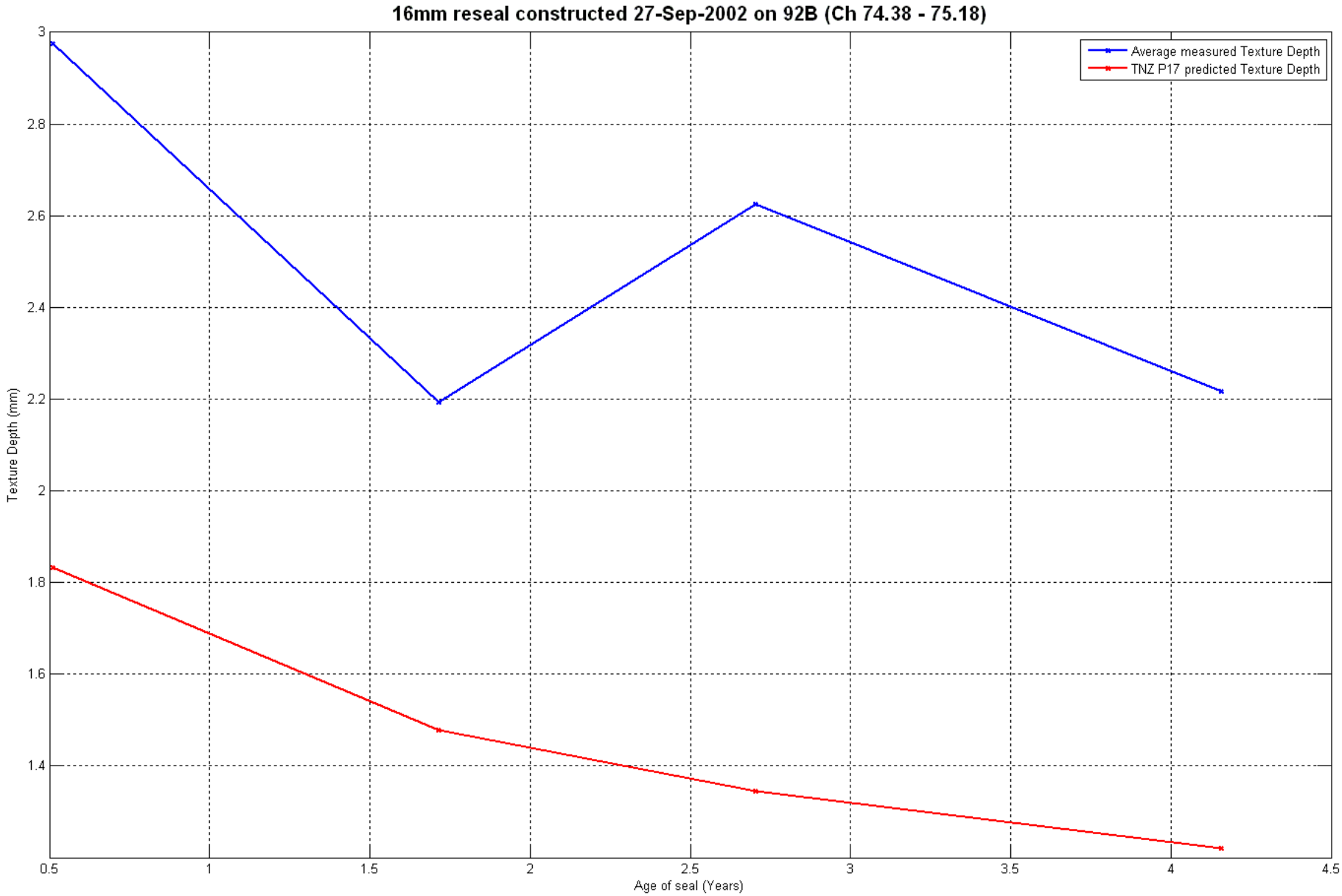

16mm reseal constructed 13-Oct-2001 on 32B (Ch 27.22 - 28.75)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.5
2
1.5
1
1
1.5
2
2.5
3
3.5
4
4.5
5

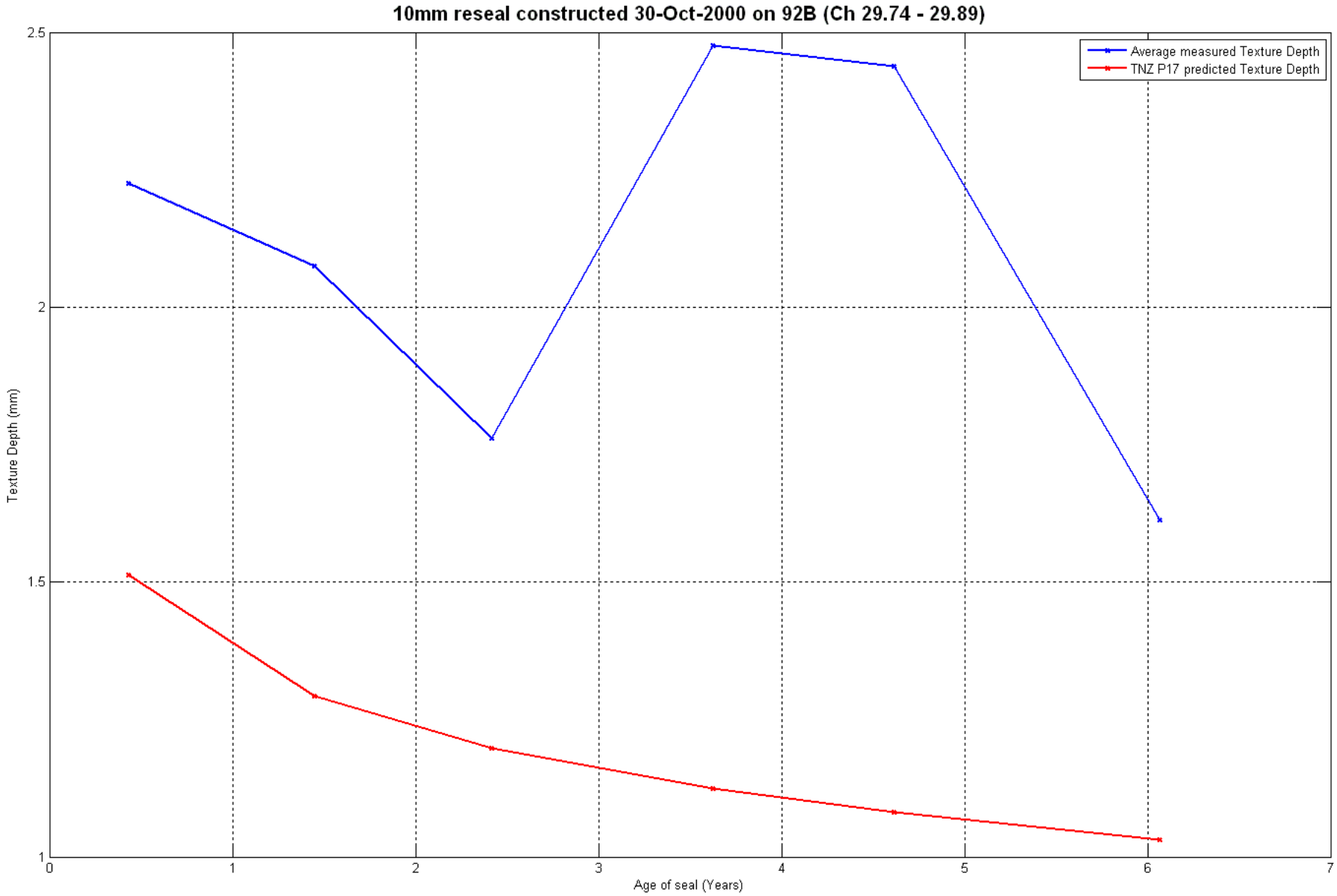

10mm reseal constructed 25-Nov-2001 on 32B (Ch 26.06 - 26.18)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
1
1.5
2
2.5
3
3.5
4
4.5
5

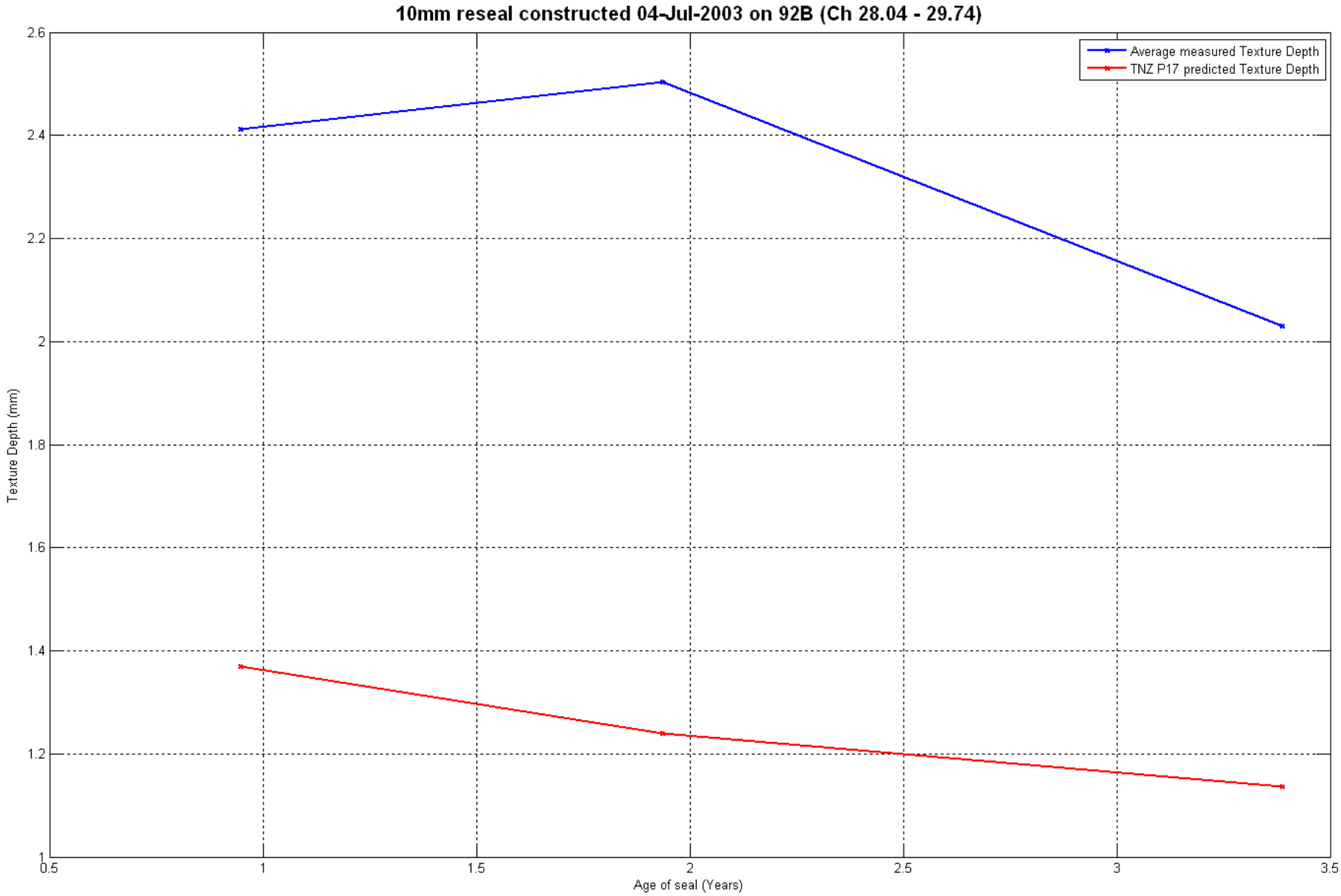

16mm reseal constructed 05-Dec-2002 on 92B (Ch 101.78 - 114.76)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
0
0.5
1
1.5
2
2.5
3
3.5
4

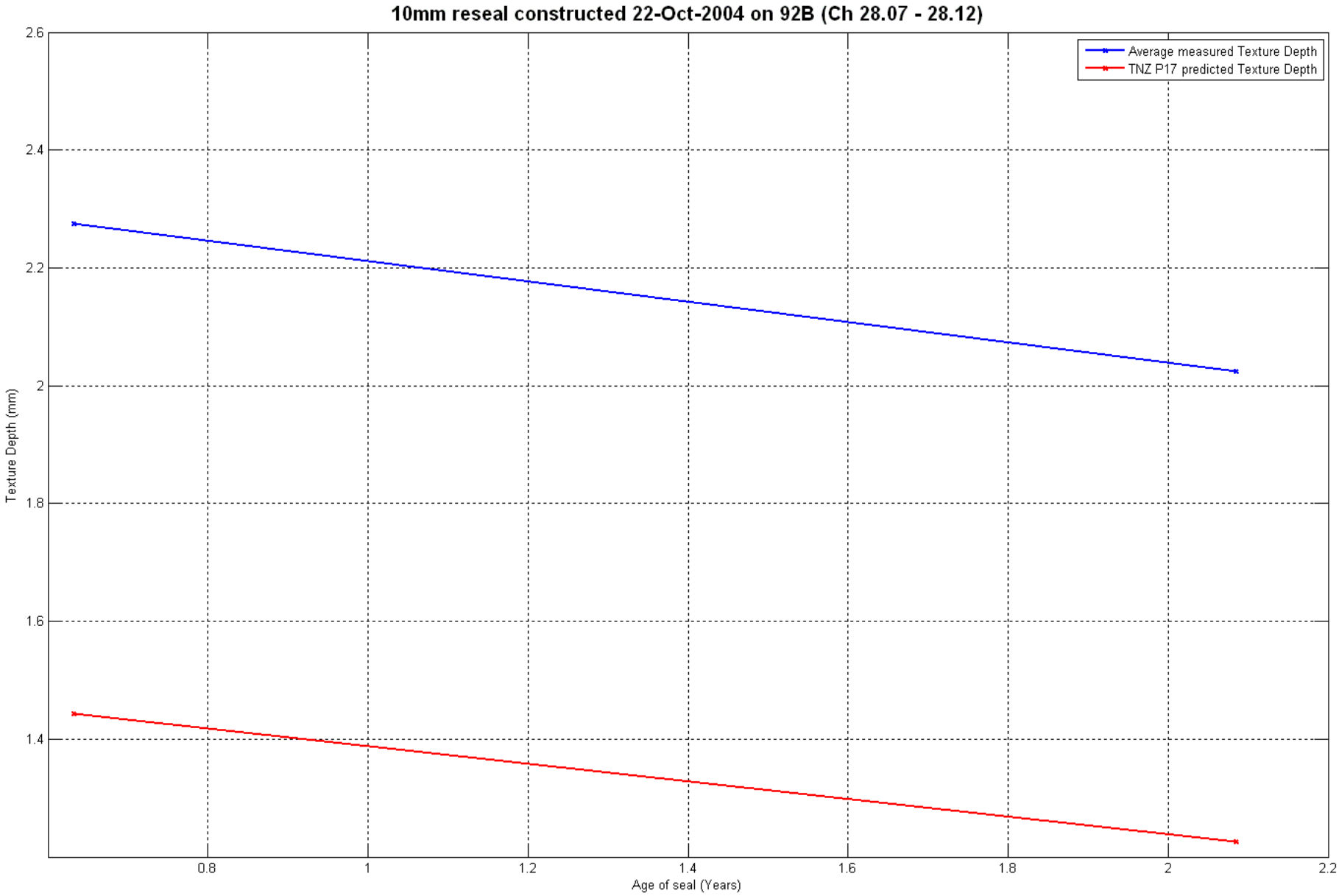

14mm reseal constructed 21-Oct-2003 on 92B (Ch 96.74 - 98.98)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
0.5
1
1.5
2
2.5
3
3.5

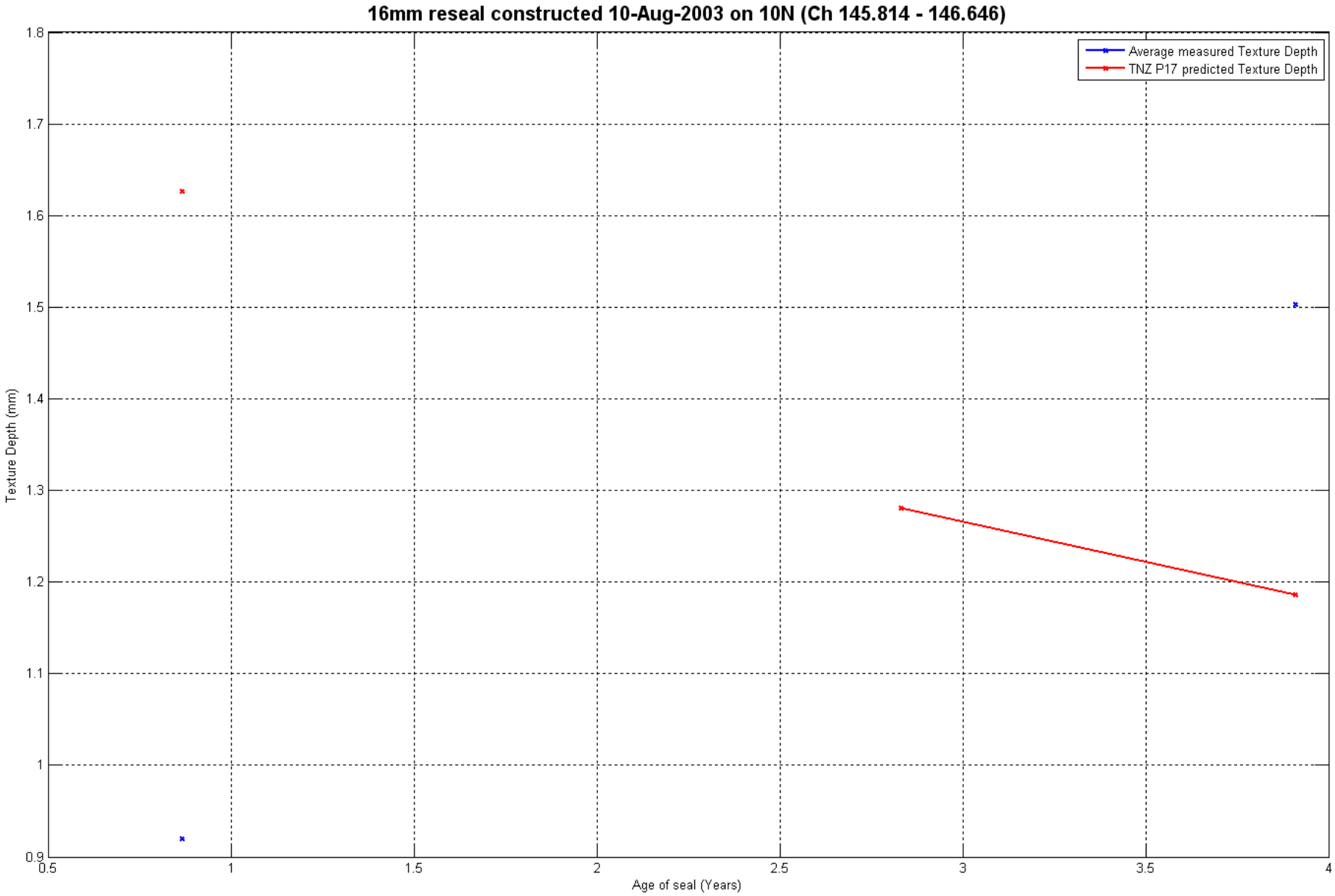

10mm reseal constructed 27-Sep-2001 on 92B (Ch 74.38 - 81.18)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5

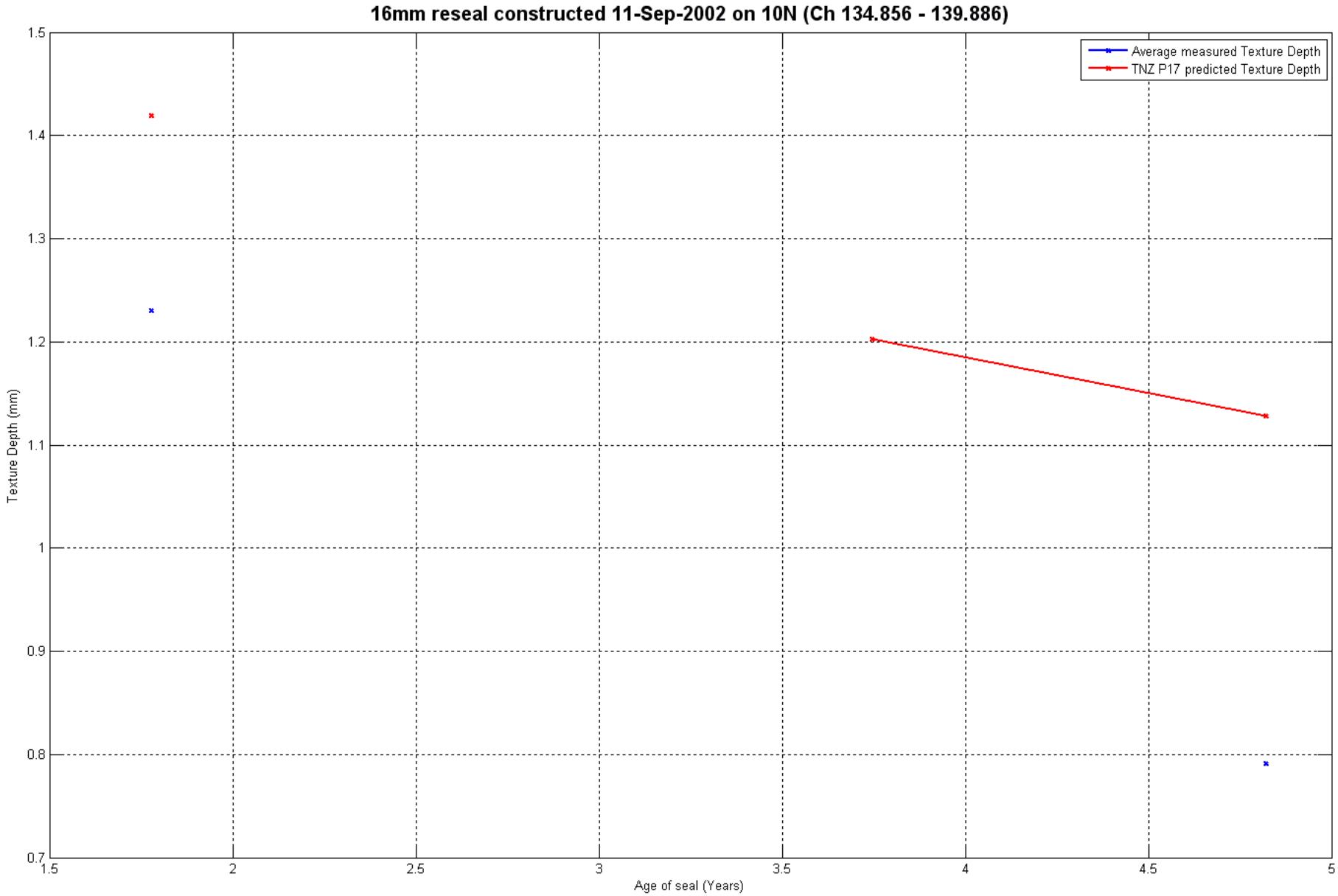

16mm reseal constructed 27-Sep-2002 on 92B (Ch 74.38 - 75.18)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
0.5
1
1.5
2
2.5
3
3.5
4
4.5

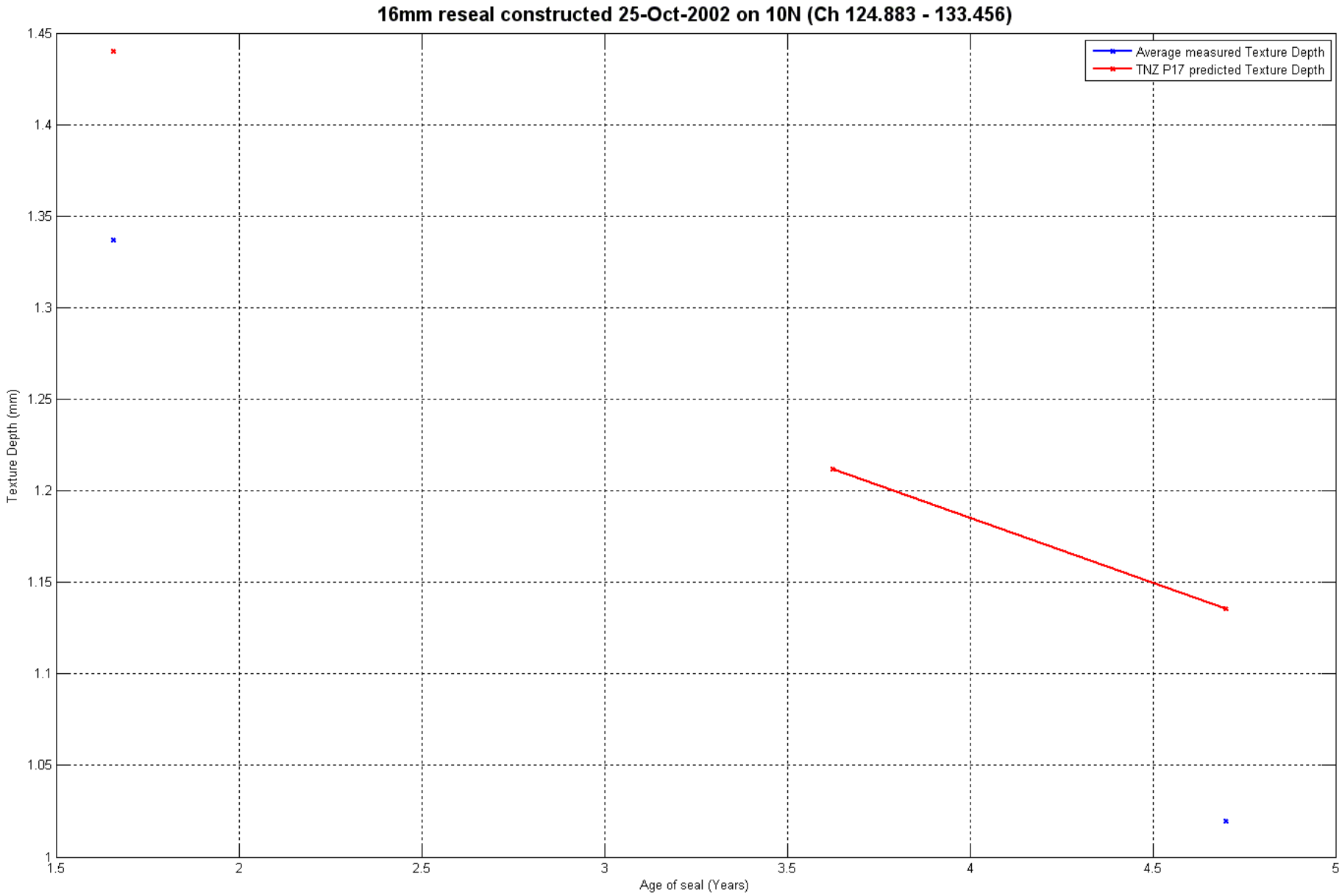

10mm reseal constructed 30-Oct-2000 on 92B (Ch 29.74 - 29.89)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.5
2
1.5
1
0
1
2
3
4
5
6
7

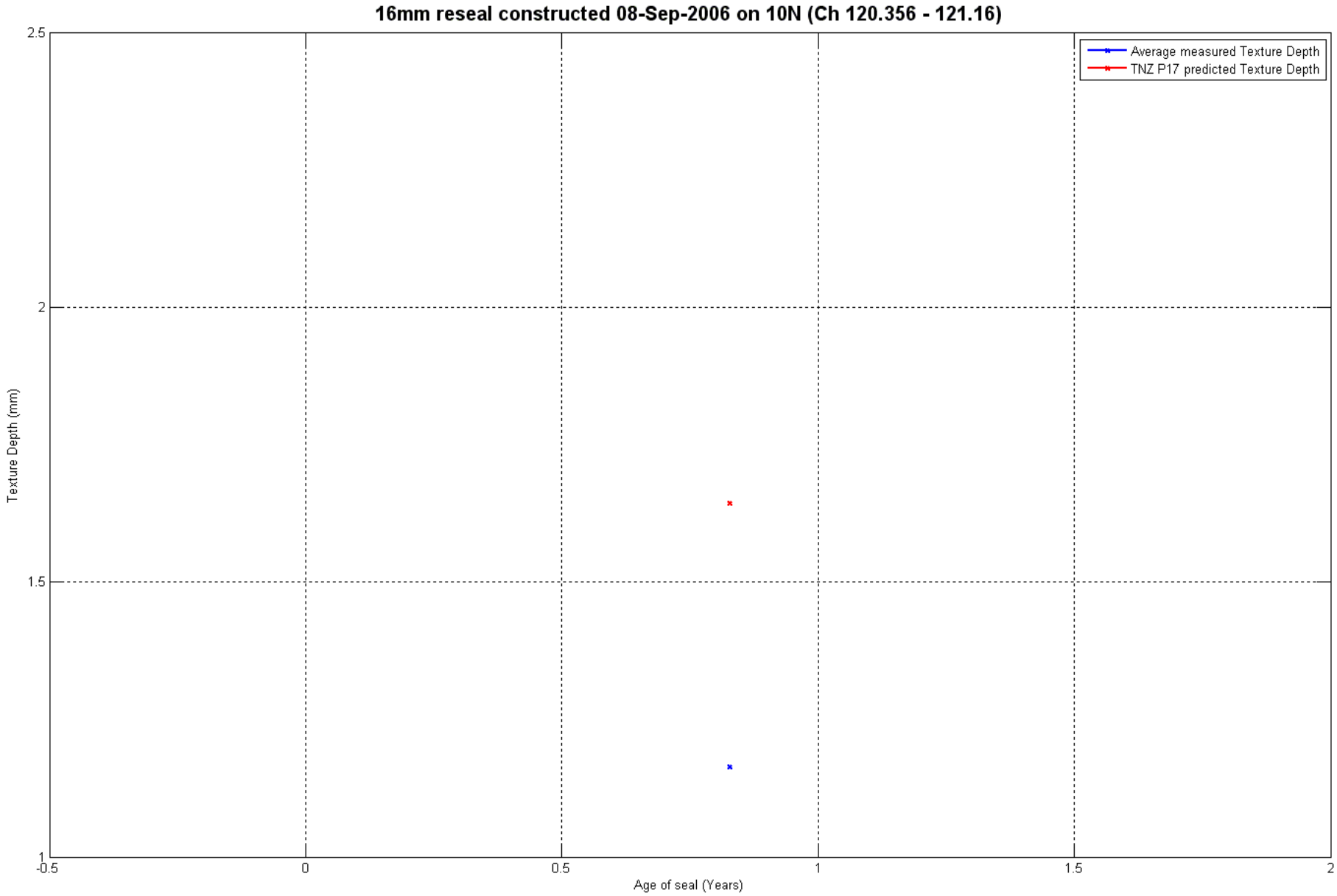

10mm reseal constructed 04-Jul-2003 on 92B (Ch 28.04 - 29.74)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.5
1
1.5
2
2.5
3
3.5

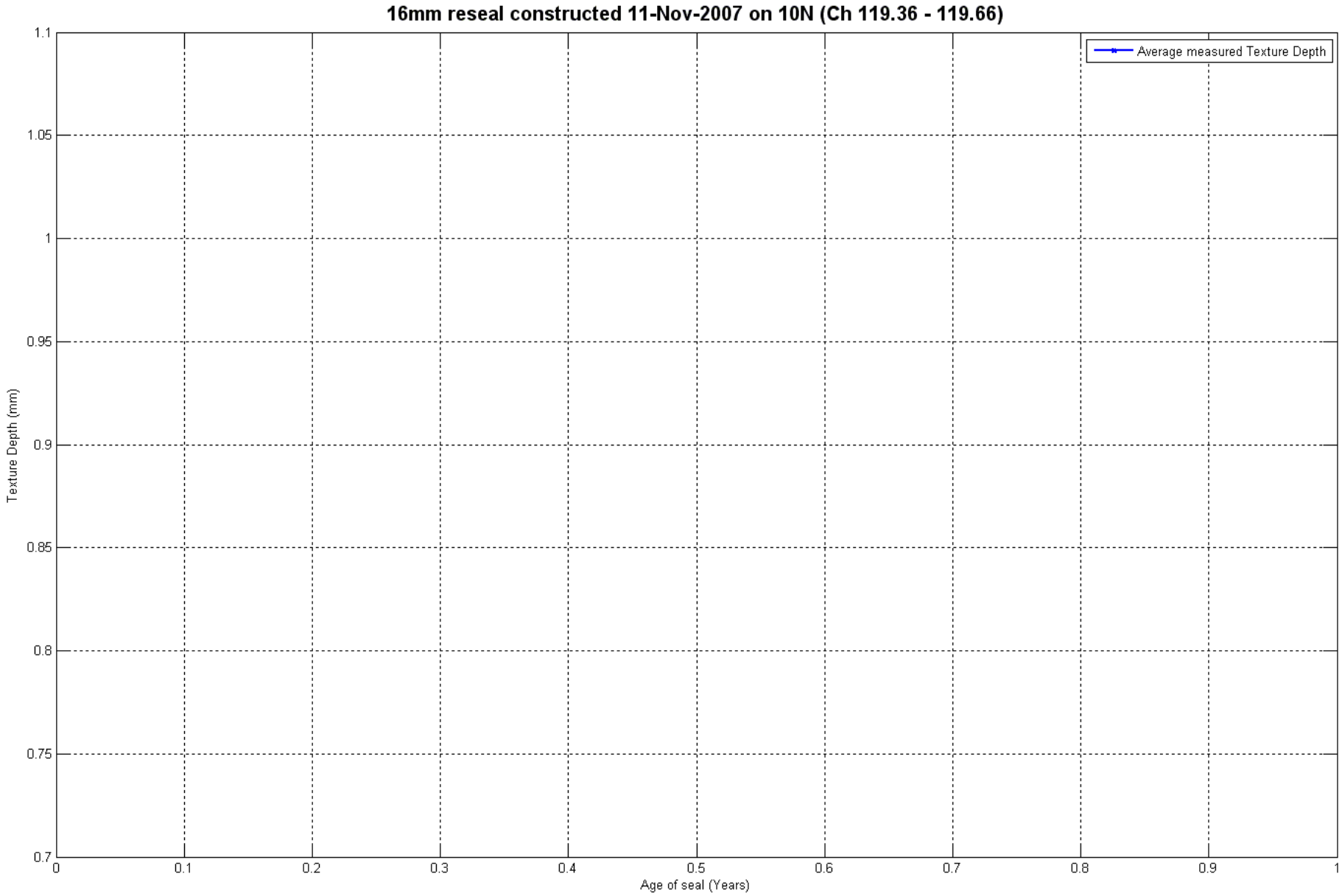

10mm reseal constructed 22-Oct-2004 on 92B (Ch 28.07 - 28.12)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
2.6
2.4
2.2
2
1.8
1.6
1.4
0.8
1
1.2
1.4
1.6
1.8
2
2.2
Age of seal (Years)

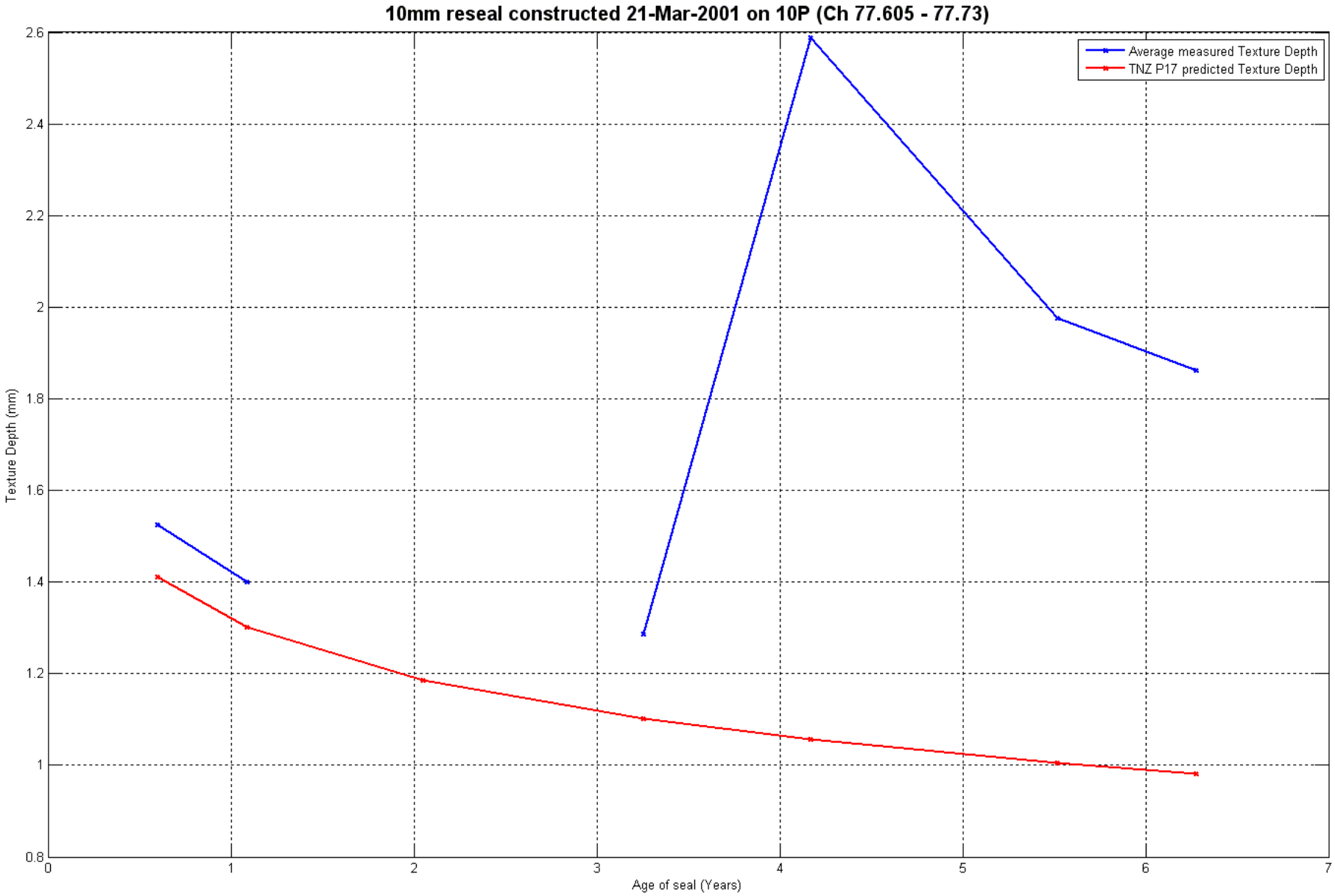

16mm reseal constructed 10-Aug-2003 on 10N (Ch 145.814 - 146.646)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.5
1
1.5
2
2.5
3
3.5
4

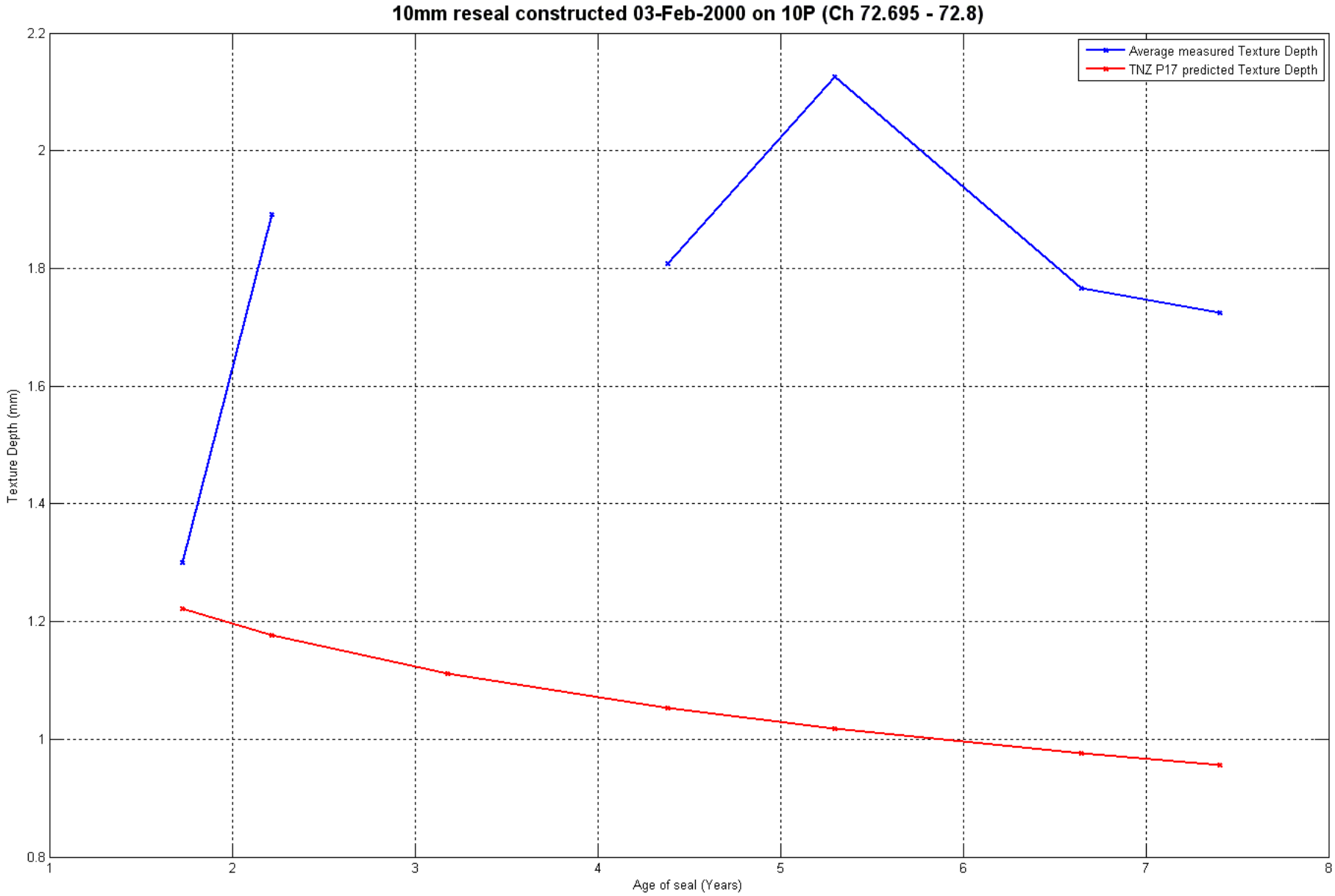

16mm reseal constructed 11-Sep-2002 on 10N (Ch 134.856 - 139.886)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
1.5
2
2.5
3
3.5
4
4.5
5

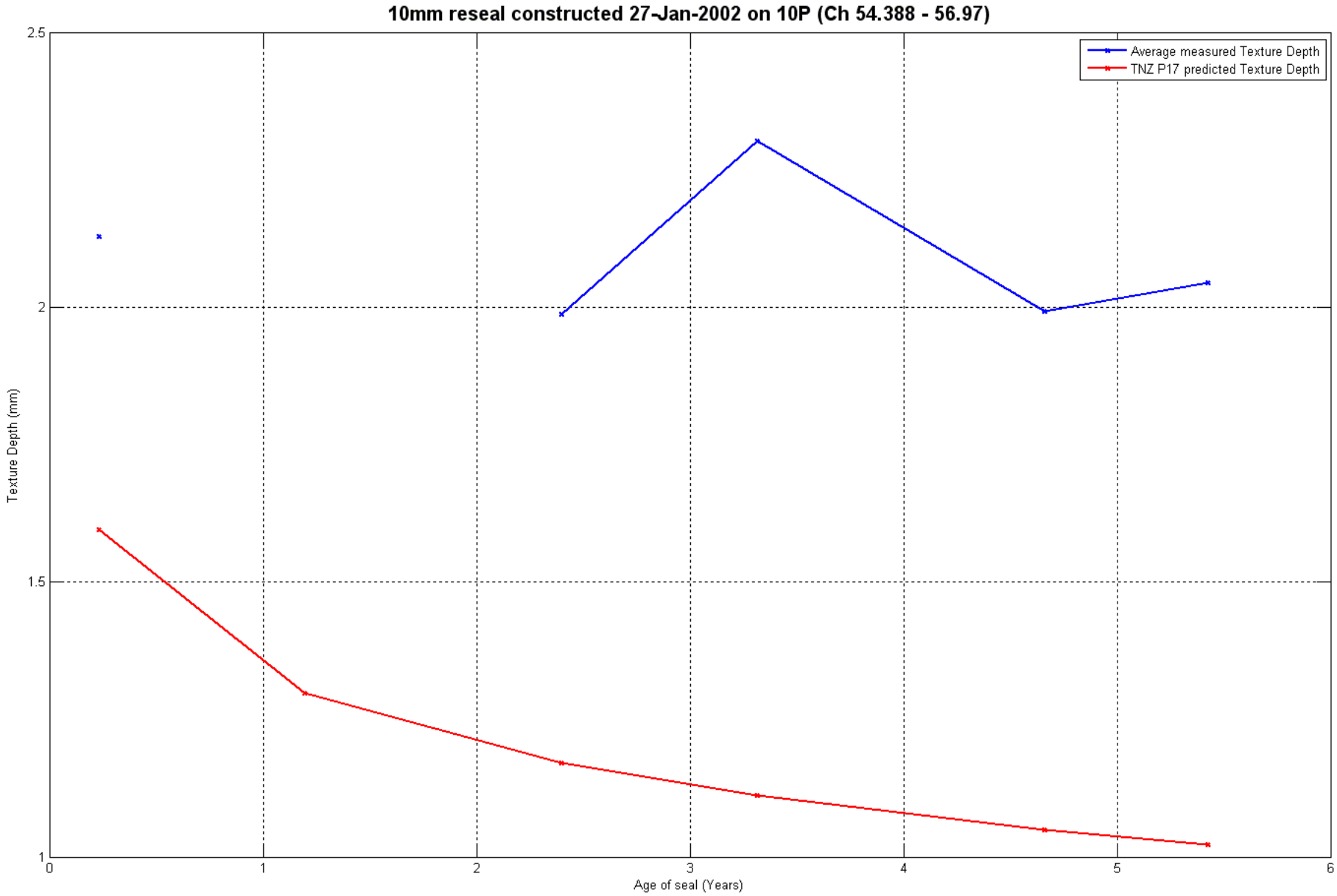

16mm reseal constructed 25-Oct-2002 on 10N (Ch 124.883 - 133.456)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
1.5
2
2.5
3
3.5
4
4.5
5

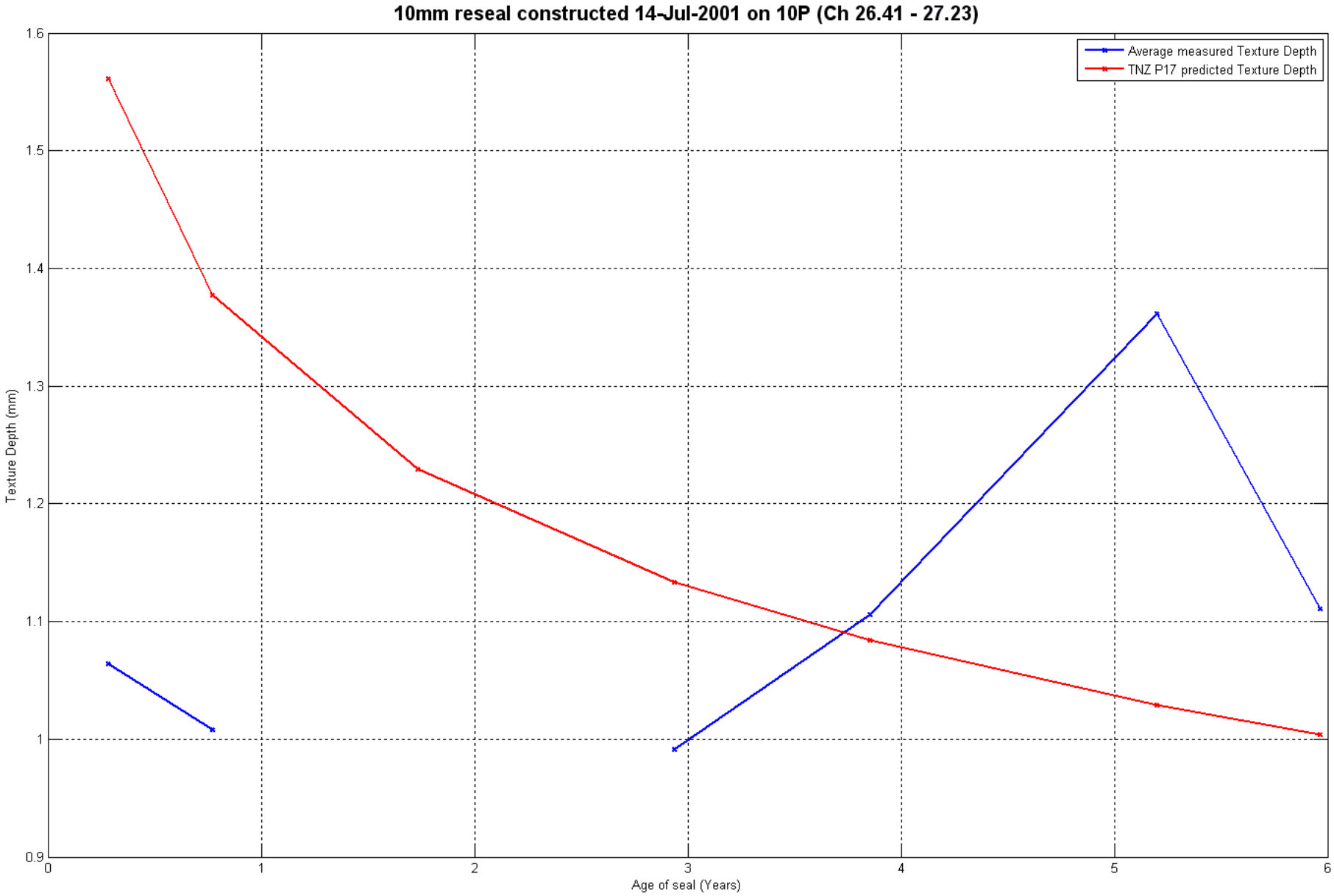

16mm reseal constructed 08-Sep-2006 on 10N (Ch 120.356 - 121.16)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
2.5
2
1.5
1
-0.5
0
0.5
1
1.5
2
Age of seal (Years)

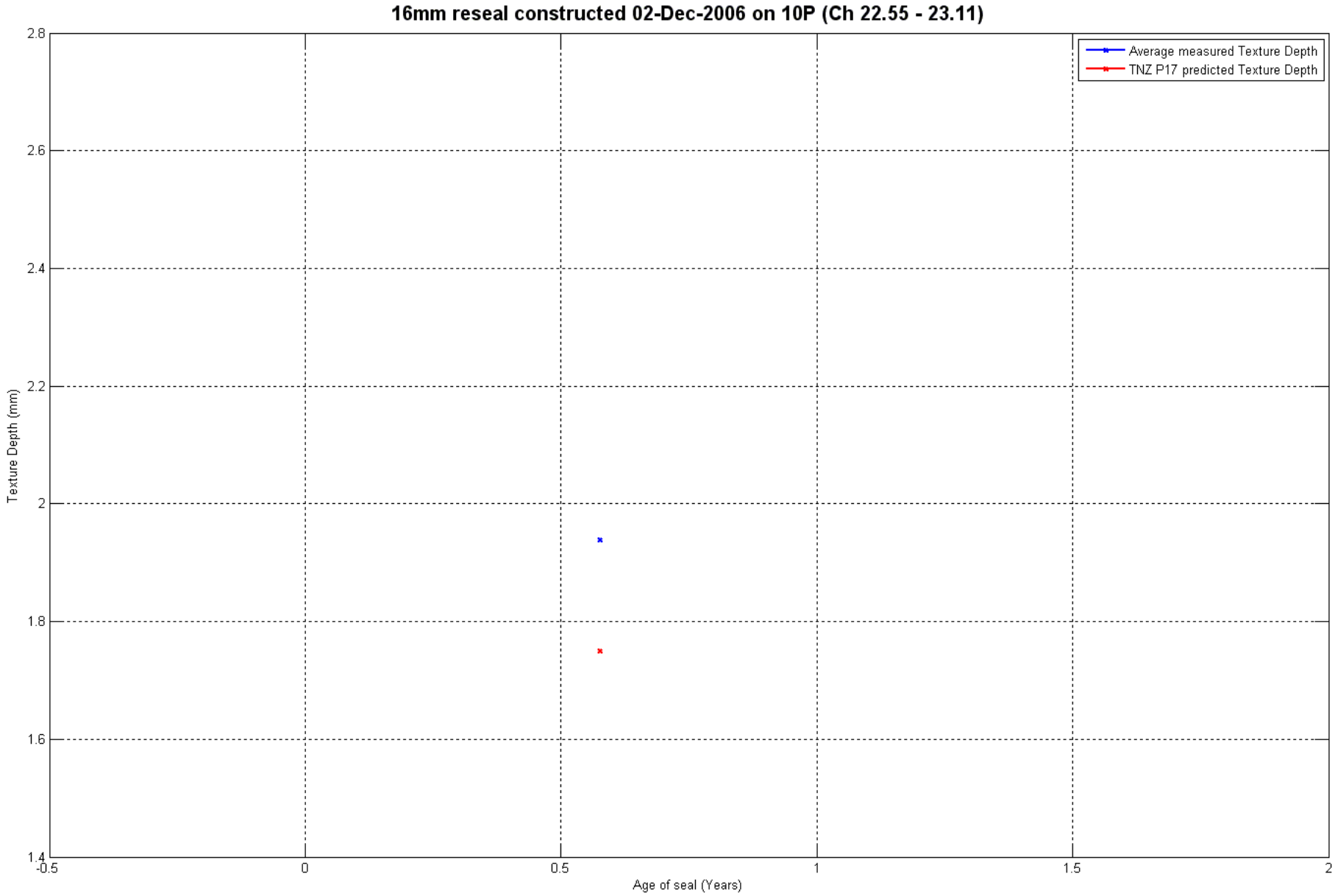

16mm reseal constructed 11-Nov-2007 on 10N (Ch 119.36 - 119.66)
Average measured Texture Depth
Texture Depth (mm)
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Age of seal (Years)

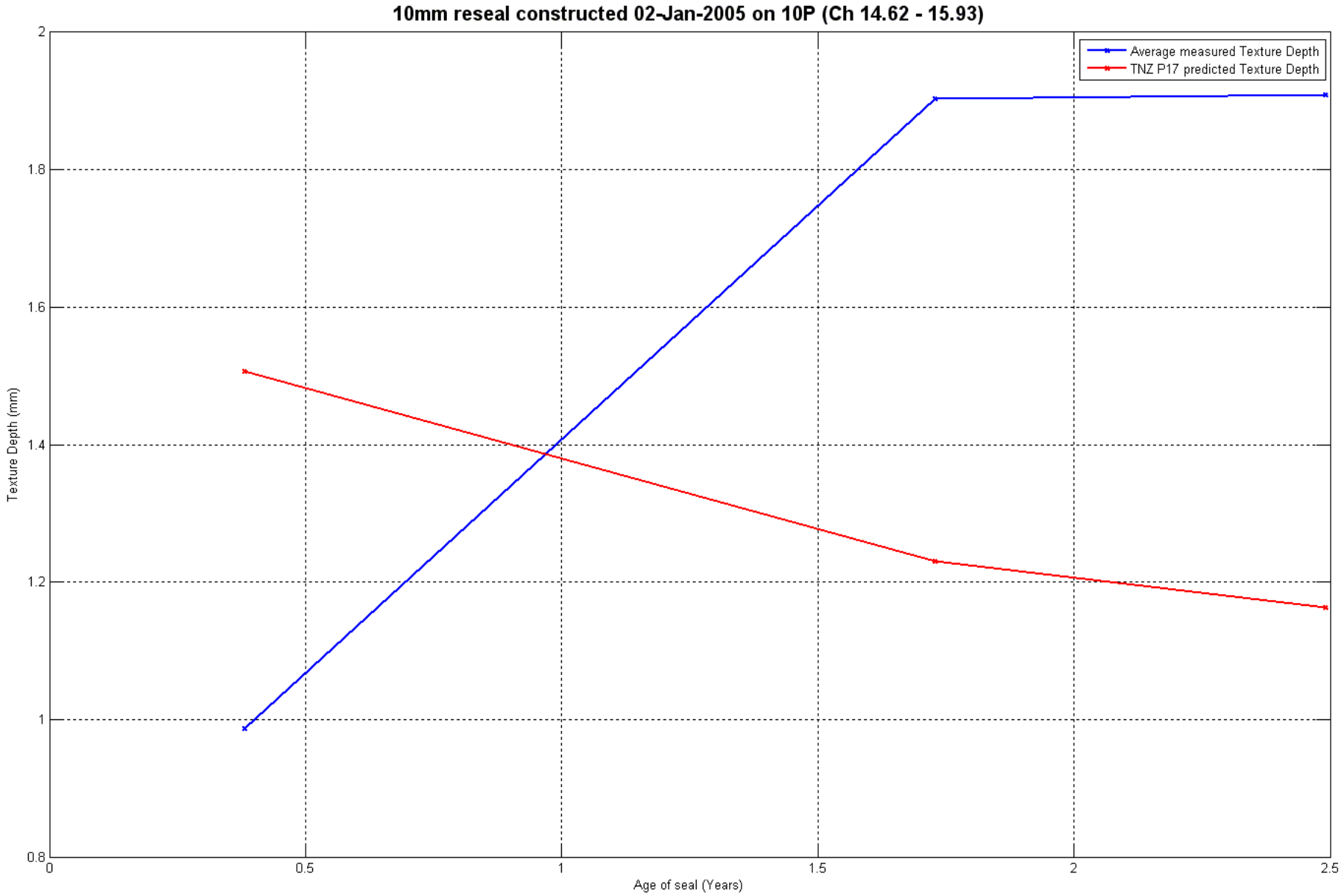

10mm reseal constructed 21-Mar-2001 on 10P (Ch 77.605 - 77.73)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0
1
2
3
4
5
6
7

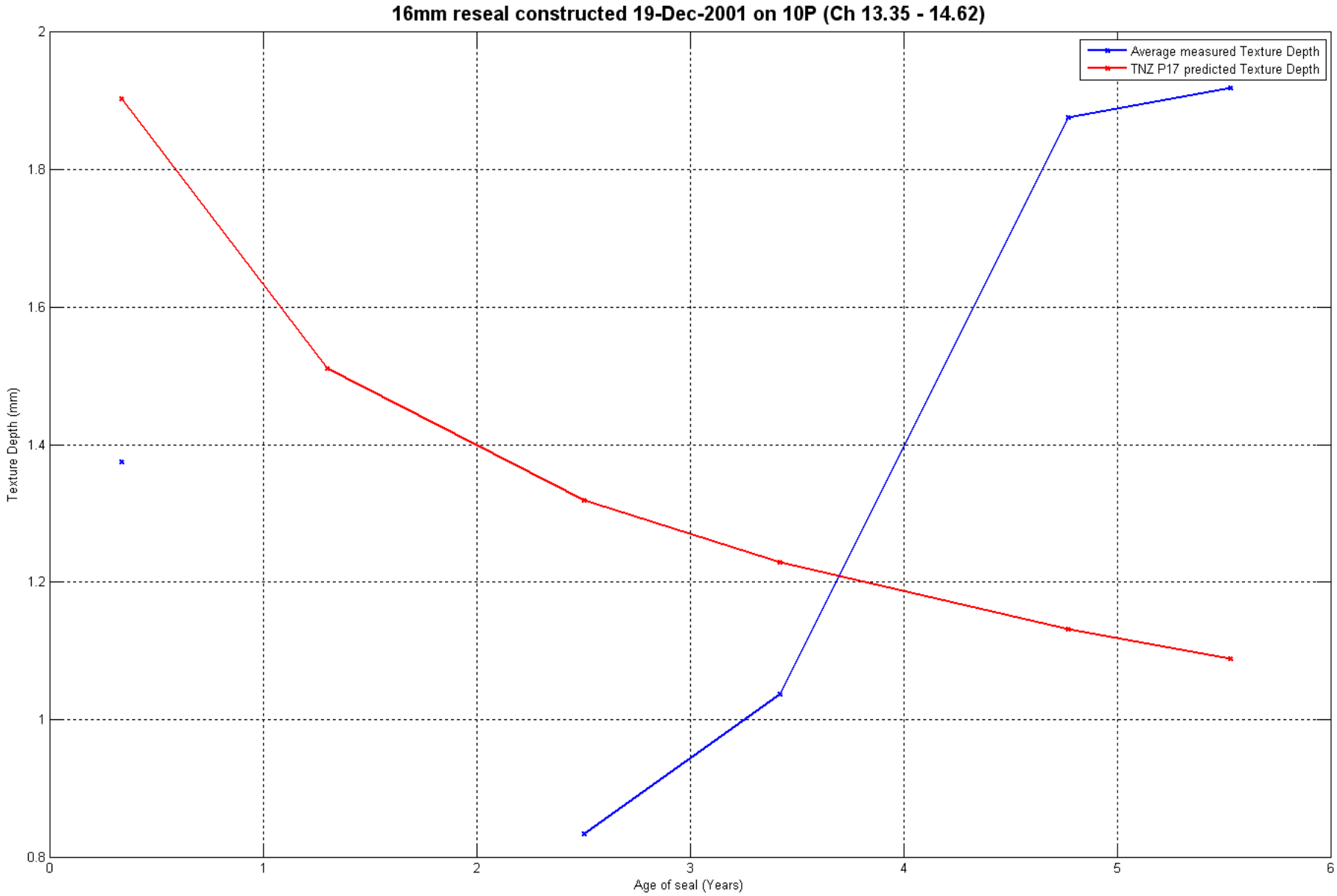

10mm reseal constructed 03-Feb-2000 on 10P (Ch 72.695 - 72.8)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
1
2
3
4
5
6
7
8

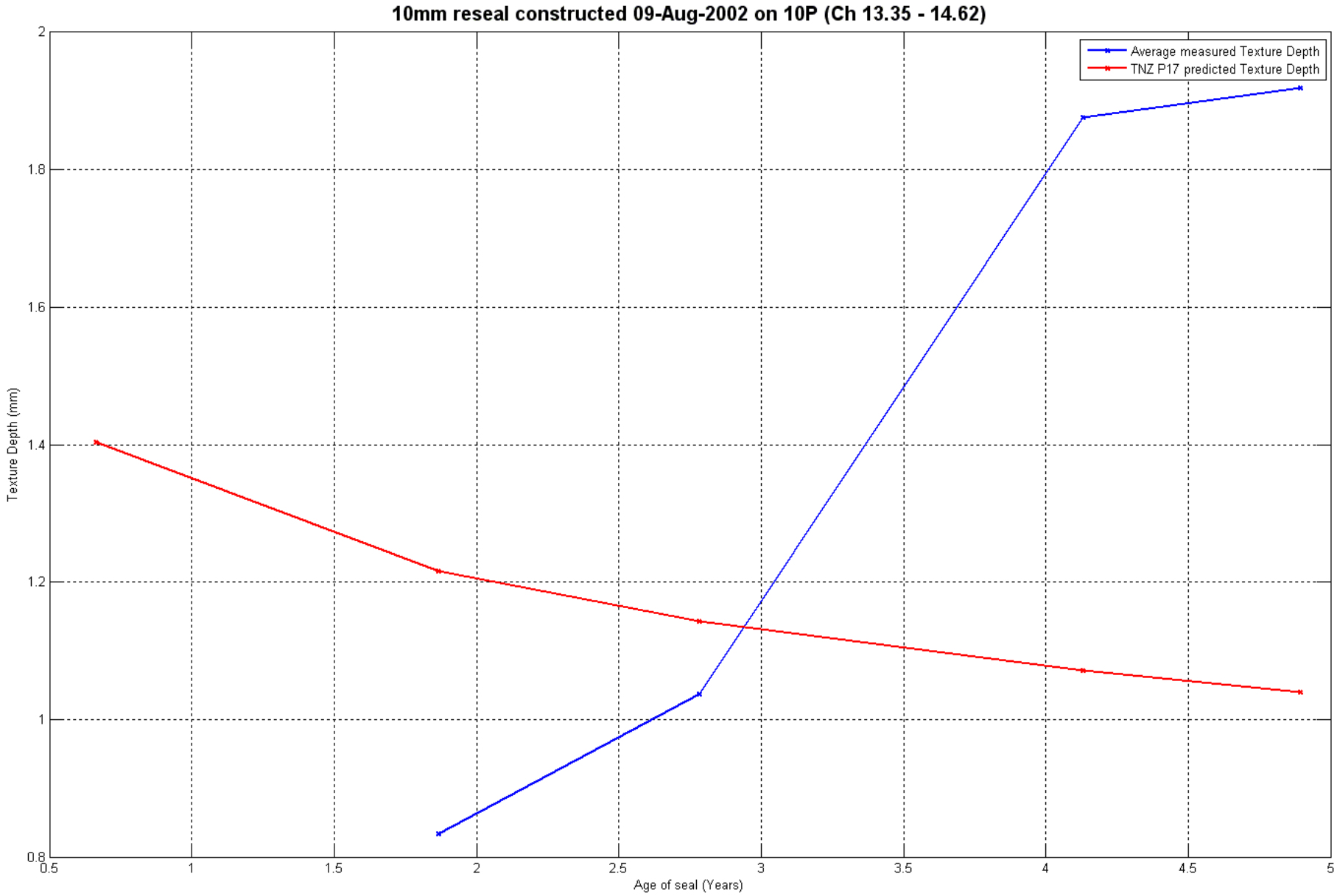

10mm reseal constructed 27-Jan-2002 on 10P (Ch 54.388 - 56.97)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.5
2
1.5
1
0
1
2
3
4
5
6

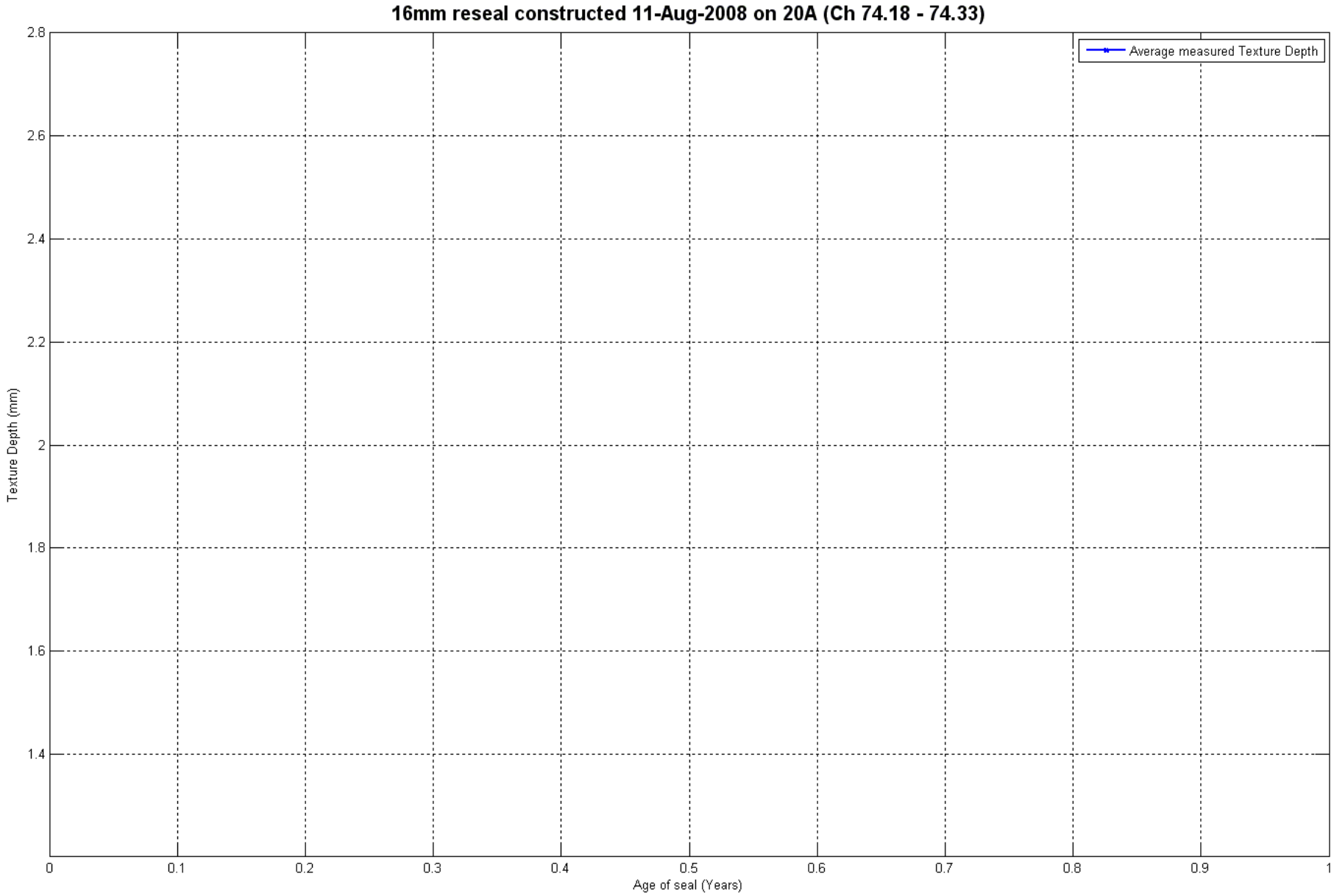

10mm reseal constructed 14-Jul-2001 on 10P (Ch 26.41 - 27.23)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0
1
2
3
4
5
6

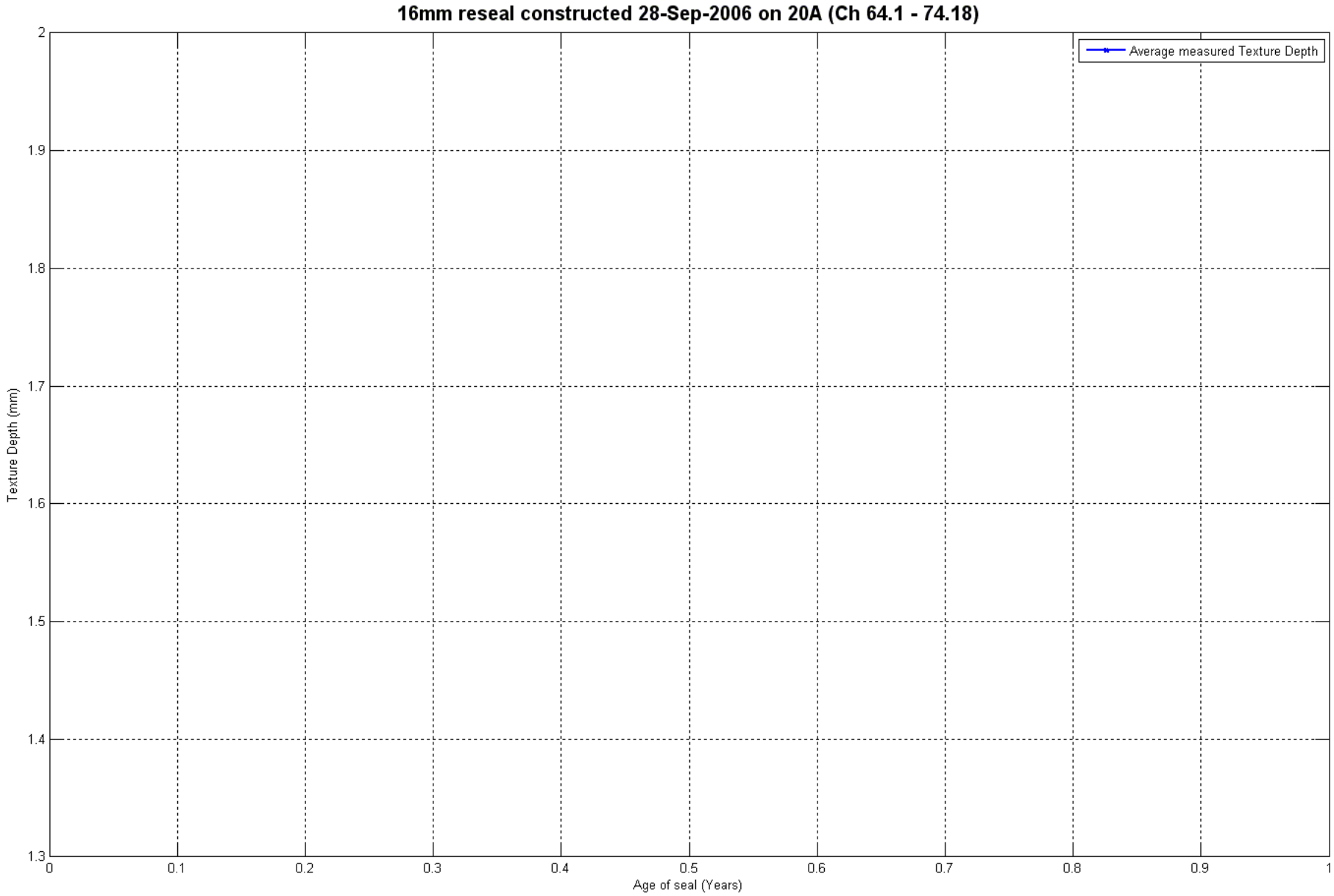

16mm reseal constructed 02-Dec-2006 on 10P (Ch 22.55 - 23.11)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
-0.5
0
0.5
1
1.5
2
Age of seal (Years)

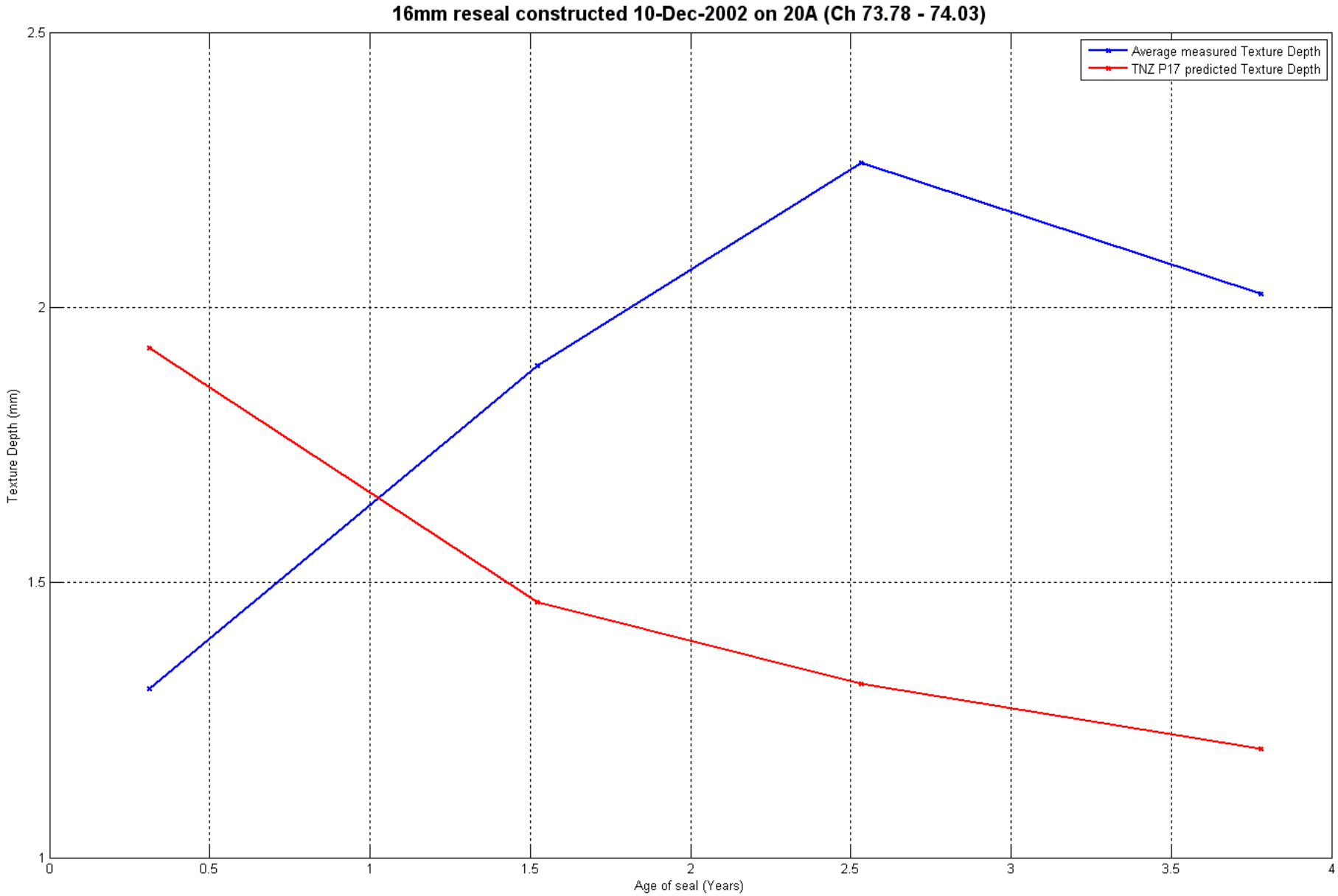

10mm reseal constructed 02-Jan-2005 on 10P (Ch 14.62 - 15.93)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2
1.8
1.6
1.4
1.2
1
0.8
0
0.5
1
1.5
2
2.5

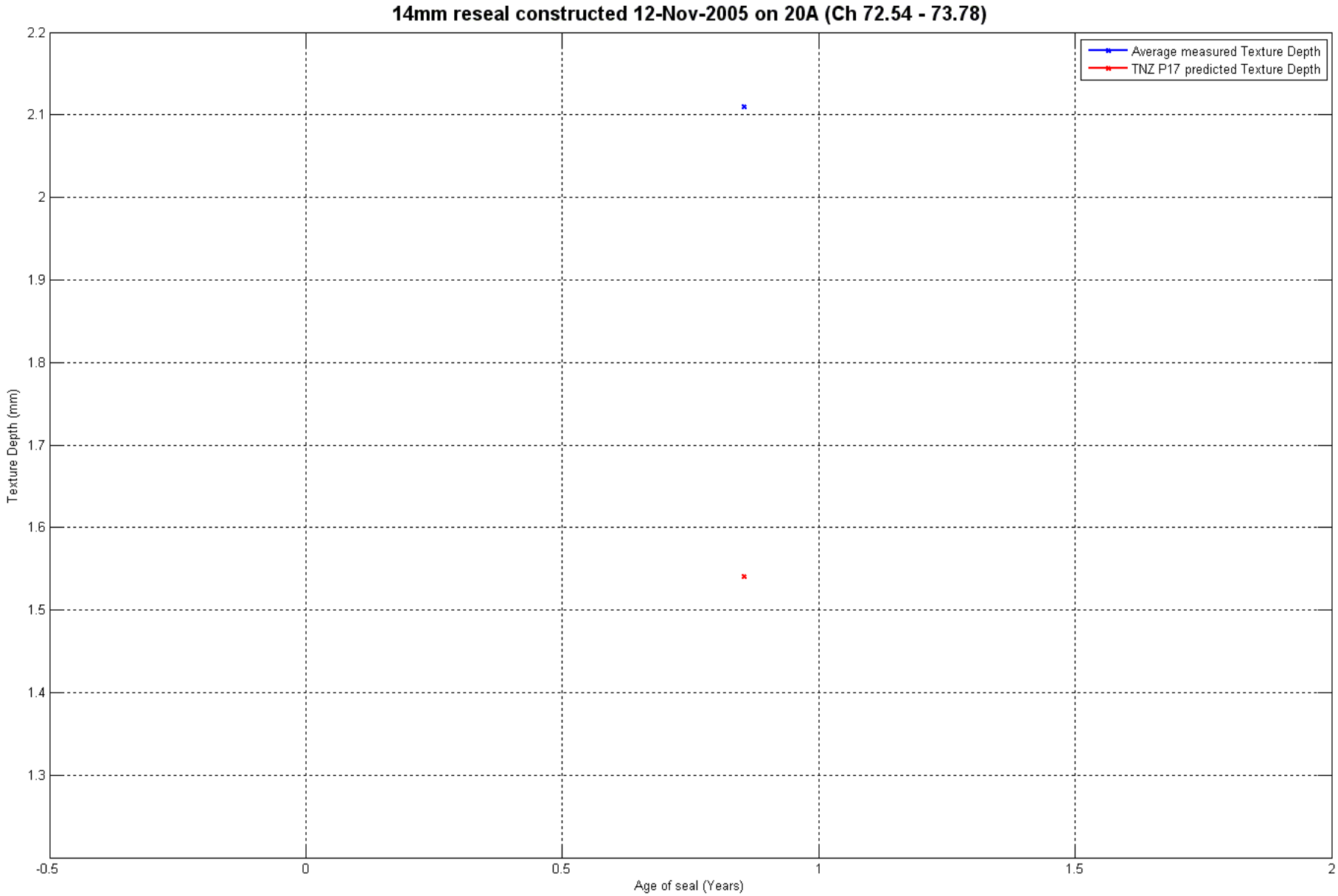

16mm reseal constructed 19-Dec-2001 on 10P (Ch 13.35 - 14.62)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2
1.8
1.6
1.4
1.2
1
0.8
0
1
2
3
4
5
6

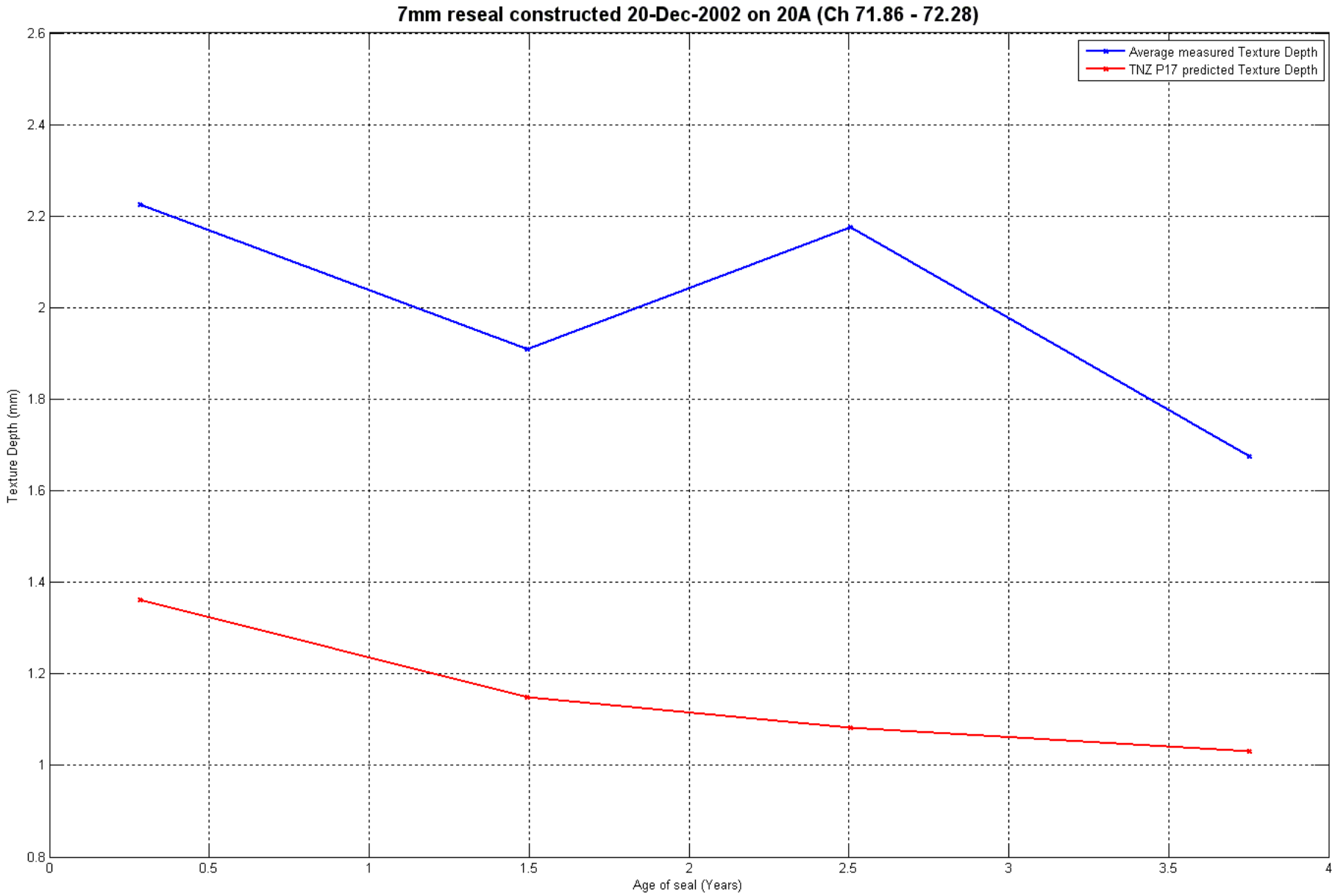

10mm reseal constructed 09-Aug-2002 on 10P (Ch 13.35 - 14.62)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2
1.8
1.6
1.4
1.2
1
0.8
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

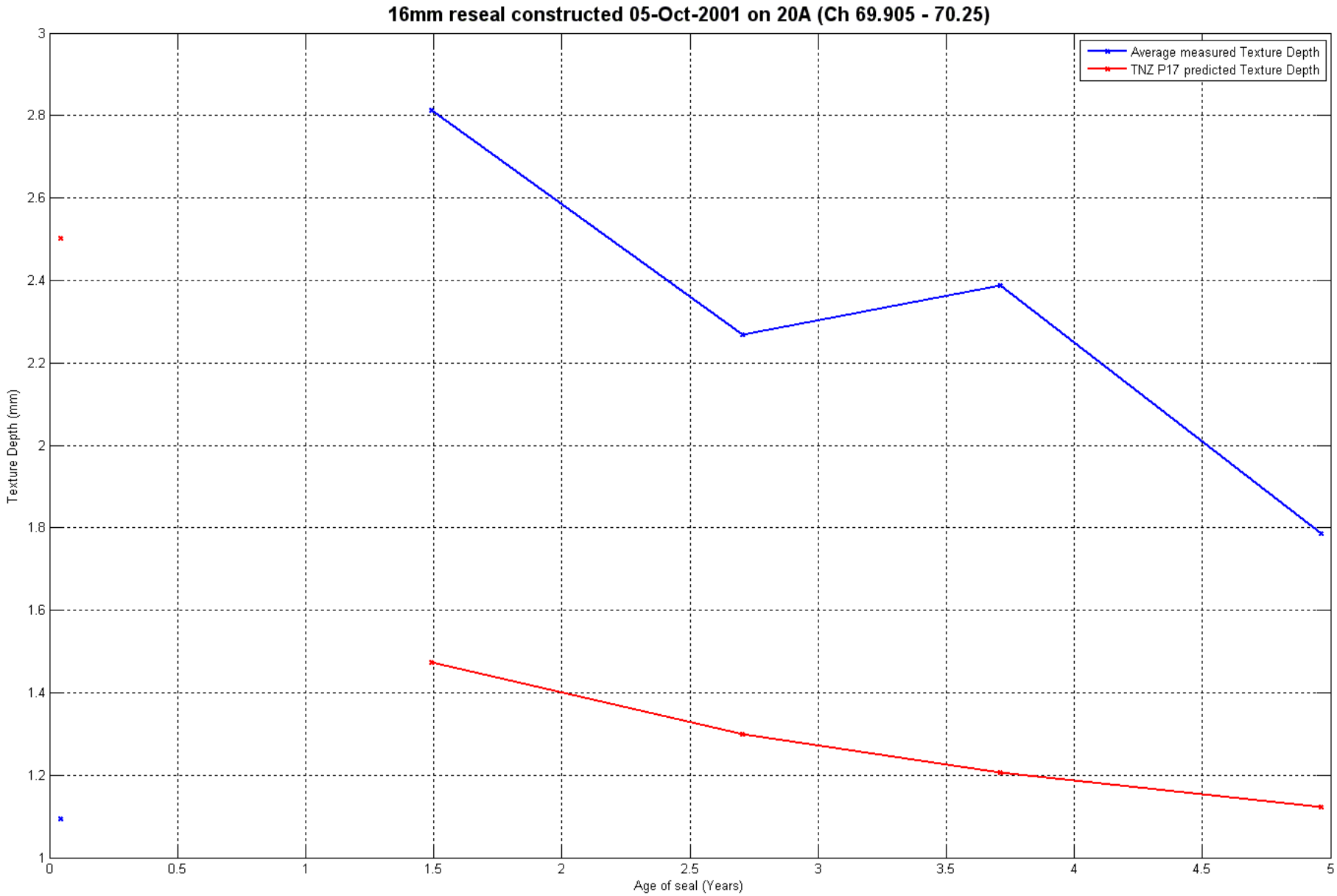

16mm reseal constructed 11-Aug-2008 on 20A (Ch 74.18 - 74.33)
Average measured Texture Depth
Texture Depth (mm)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Age of seal (Years)

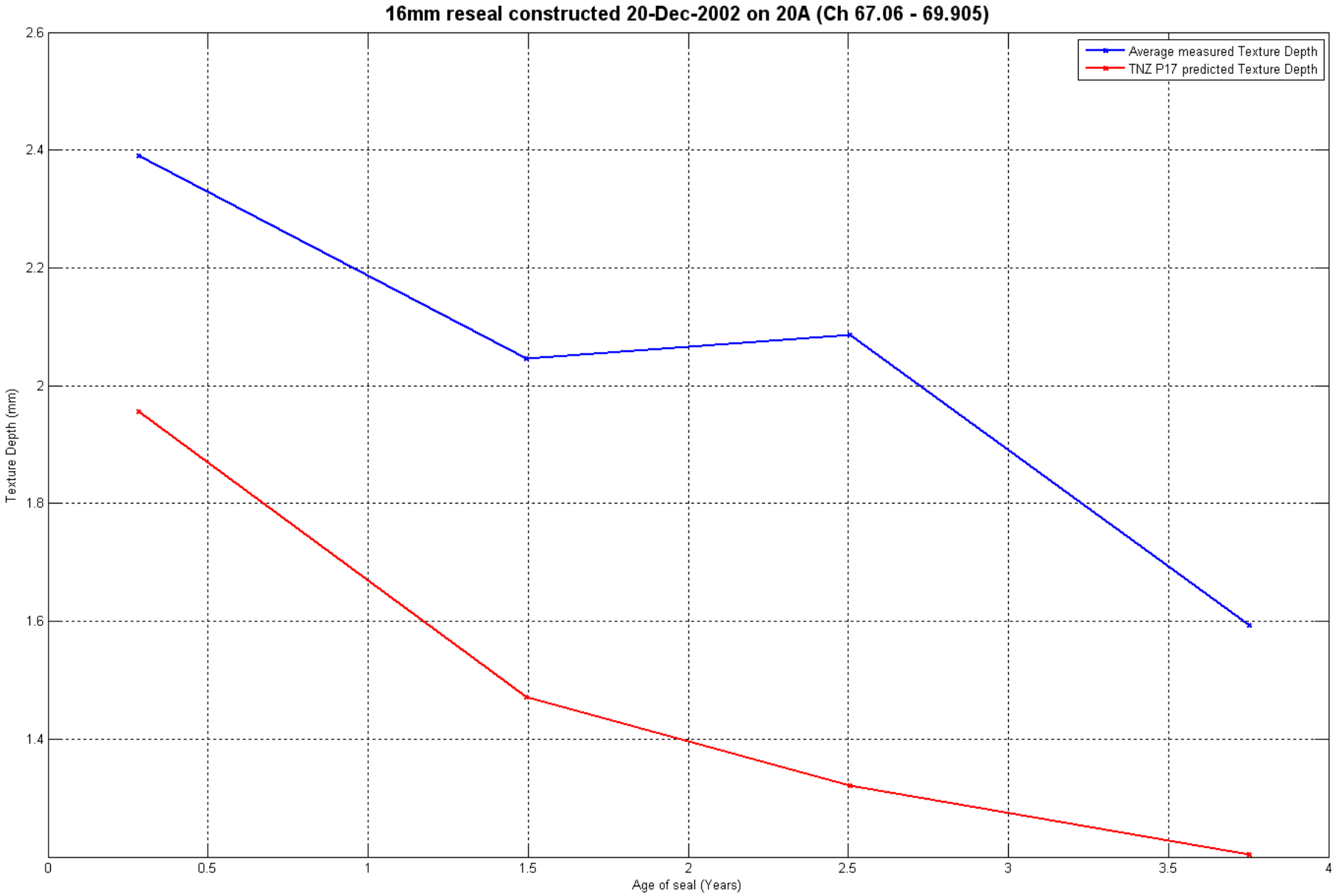

16mm reseal constructed 28-Sep-2006 on 20A (Ch 64.1 - 74.18)
Average measured Texture Depth
Texture Depth (mm)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Age of seal (Years)

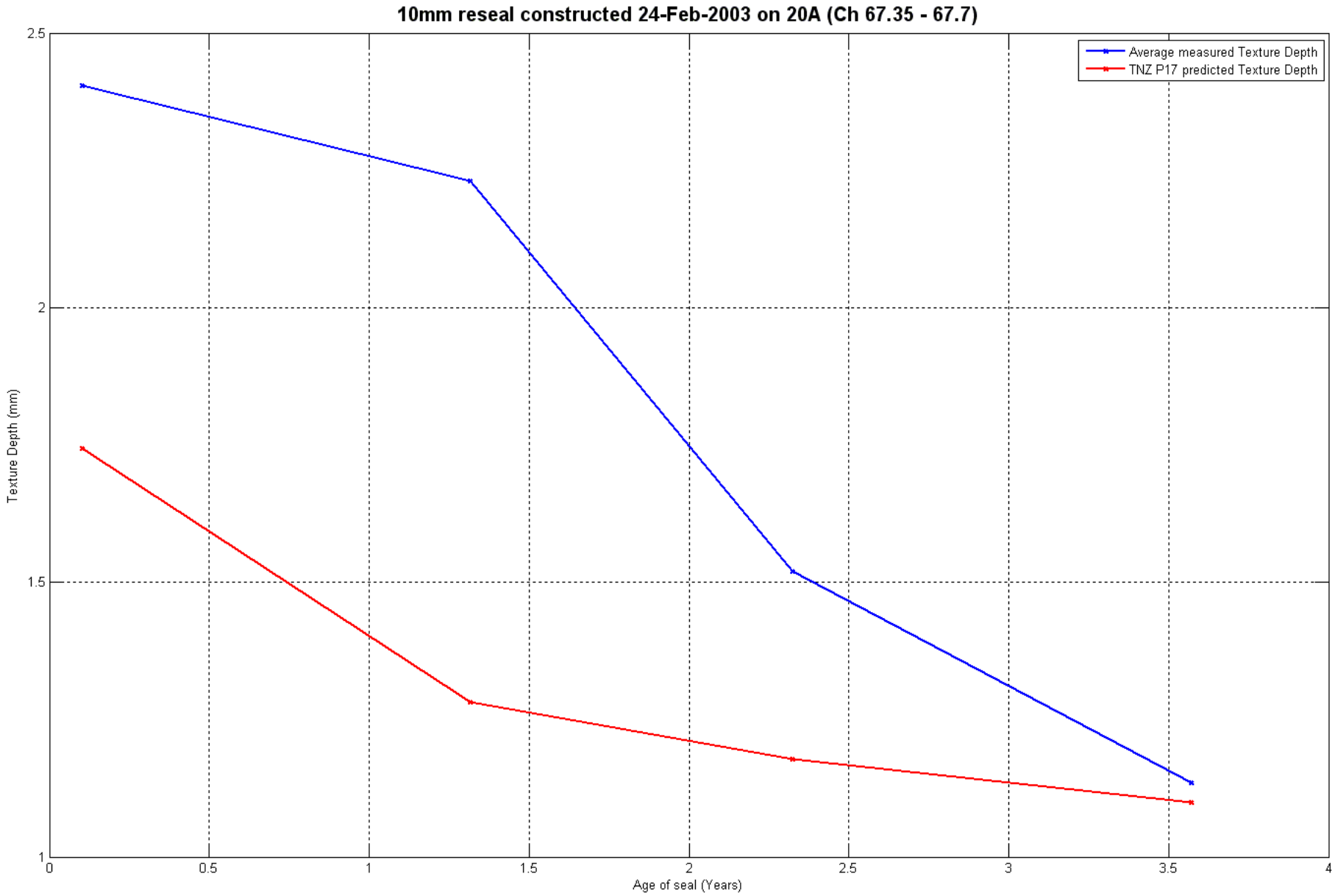

16mm reseal constructed 10-Dec-2002 on 20A (Ch 73.78 - 74.03)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.5
2
1.5
1
0
0.5
1
1.5
2
2.5
3
3.5
4

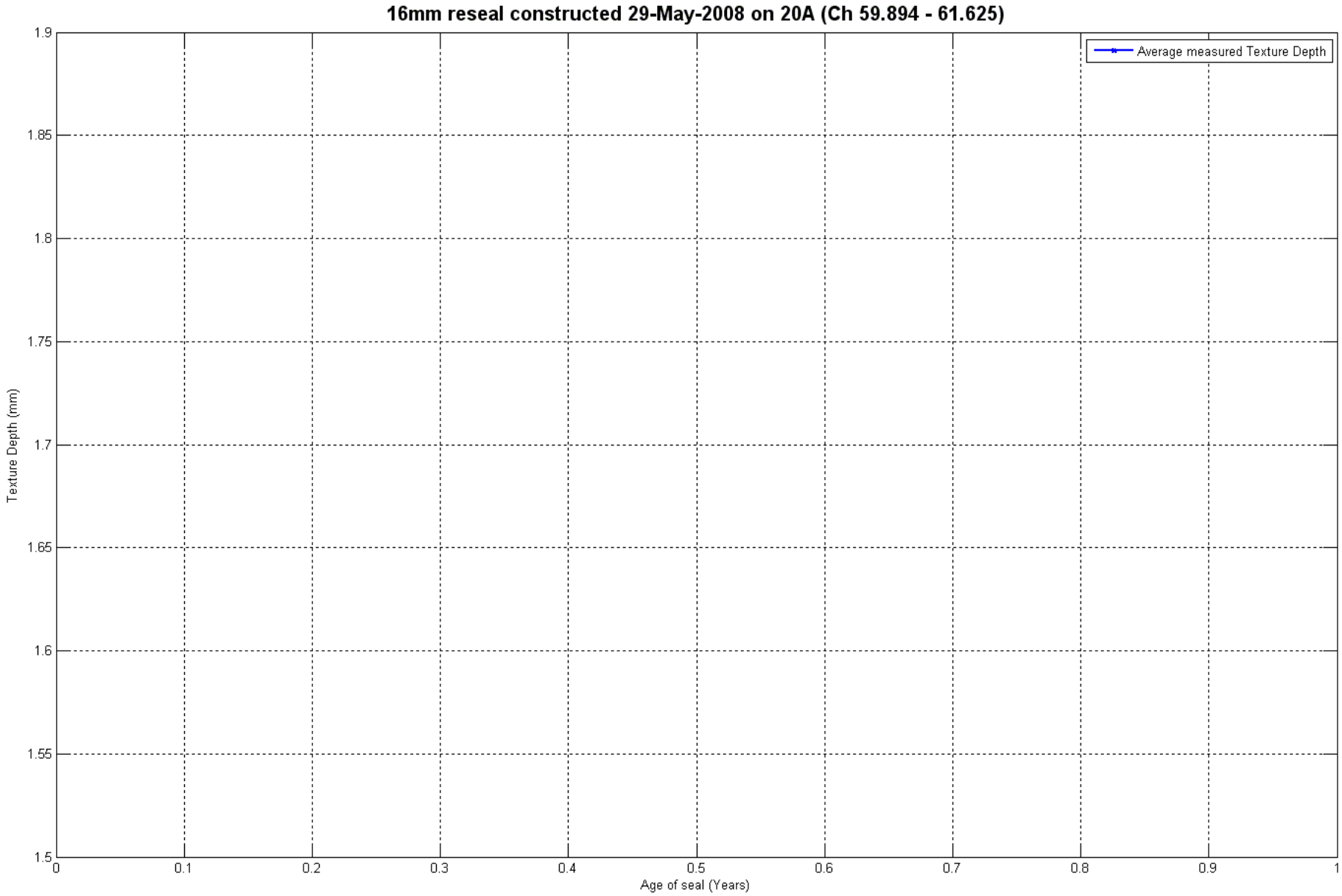

14mm reseal constructed 12-Nov-2005 on 20A (Ch 72.54 - 73.78)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
-0.5
0
0.5
1
1.5
2
Age of seal (Years)

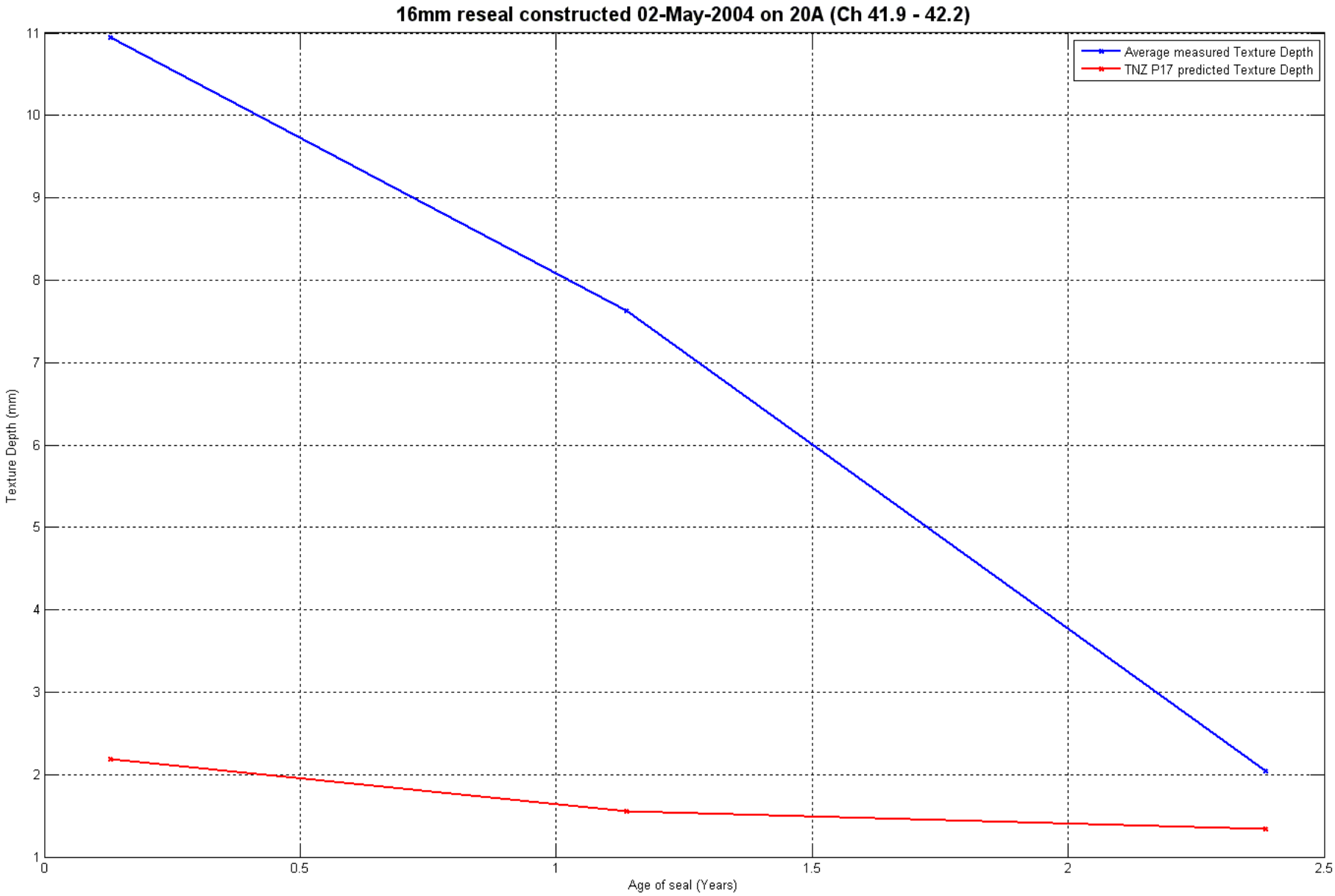

7mm reseal constructed 20-Dec-2002 on 20A (Ch 71.86 - 72.28)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0
0.5
1
1.5
2
2.5
3
3.5
4

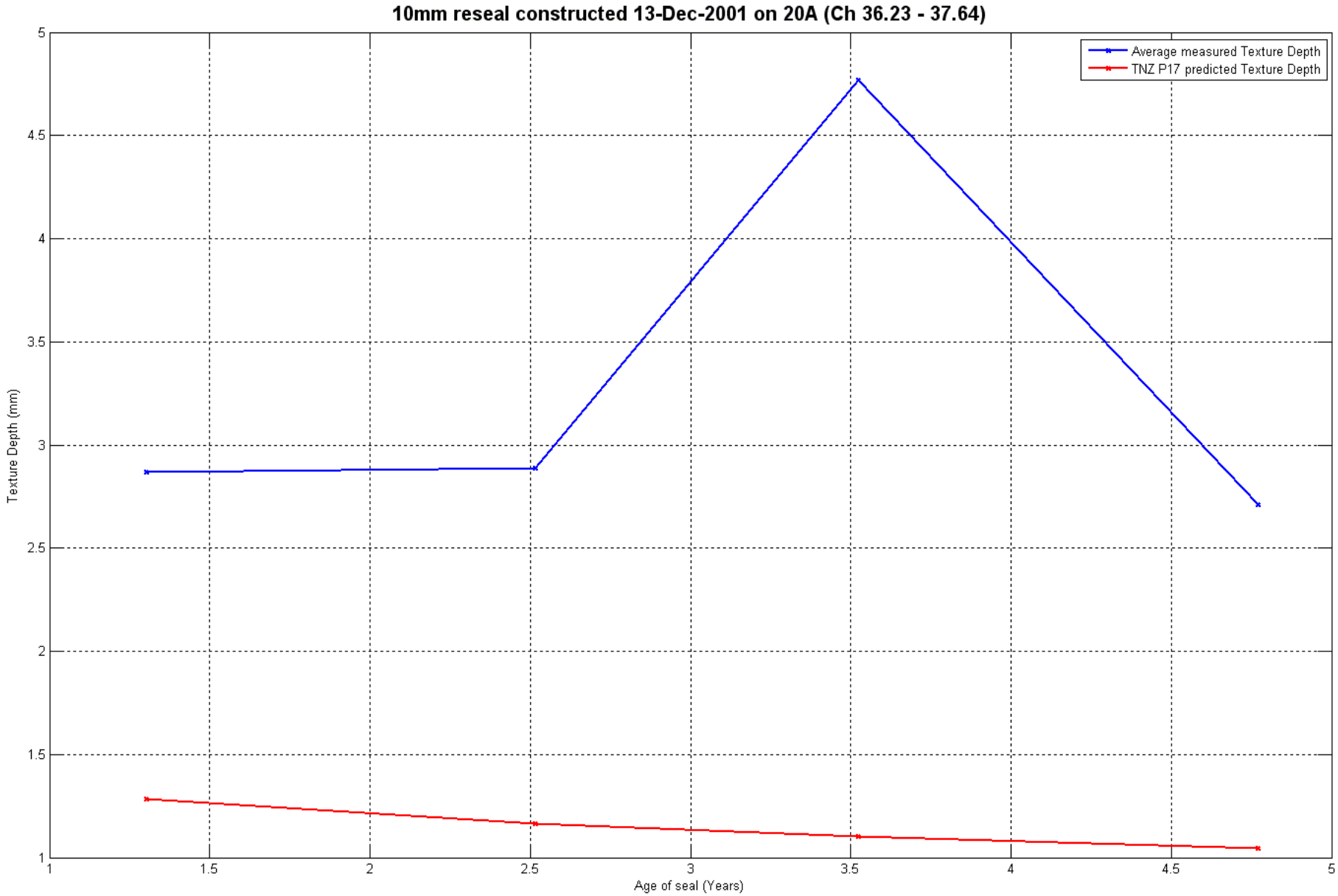

16mm reseal constructed 05-Oct-2001 on 20A (Ch 69.905 - 70.25)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

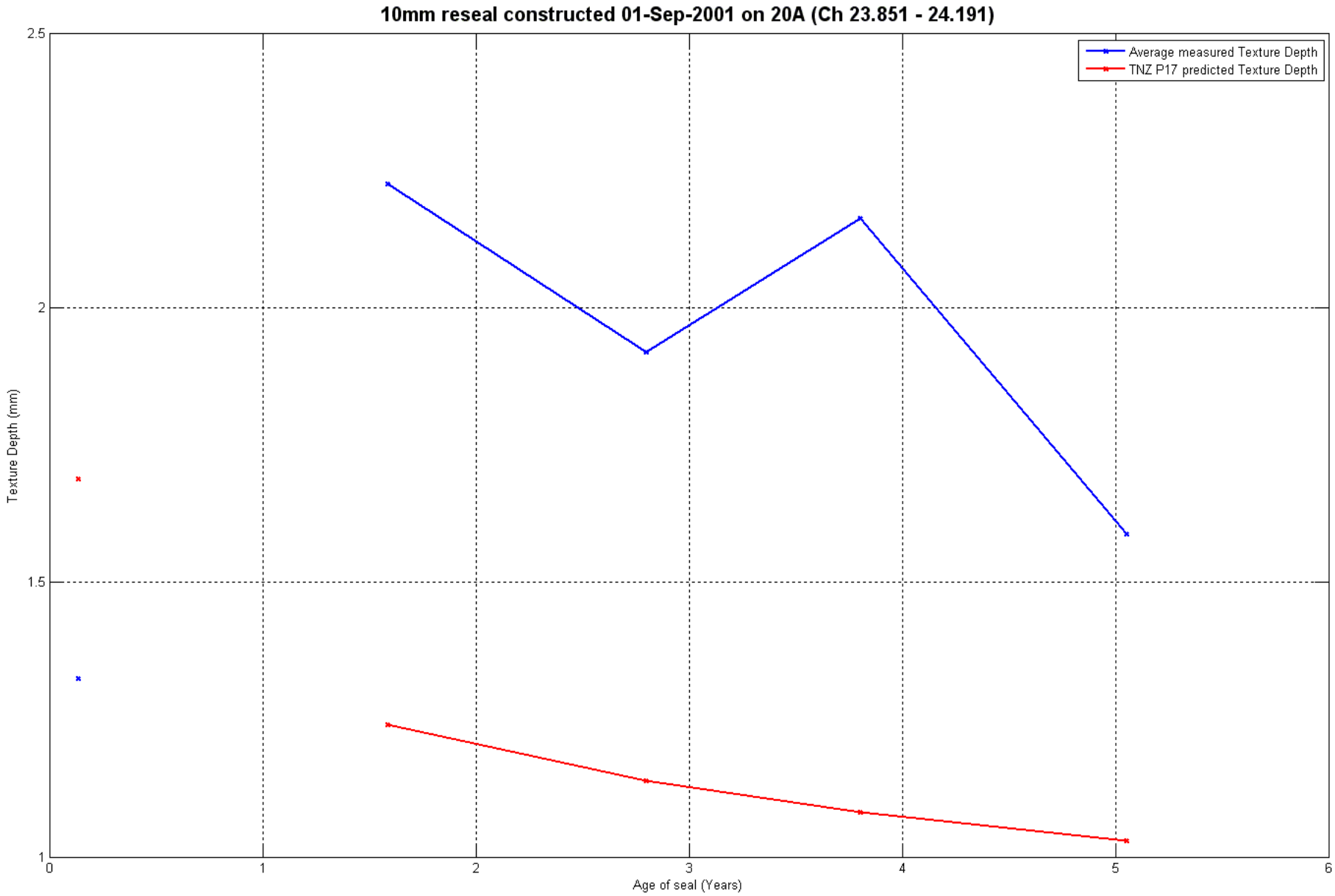

16mm reseal constructed 20-Dec-2002 on 20A (Ch 67.06 - 69.905)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.6
2.4
2.2
2
1.8
1.6
1.4
0
0.5
1
1.5
2
2.5
3
3.5
4

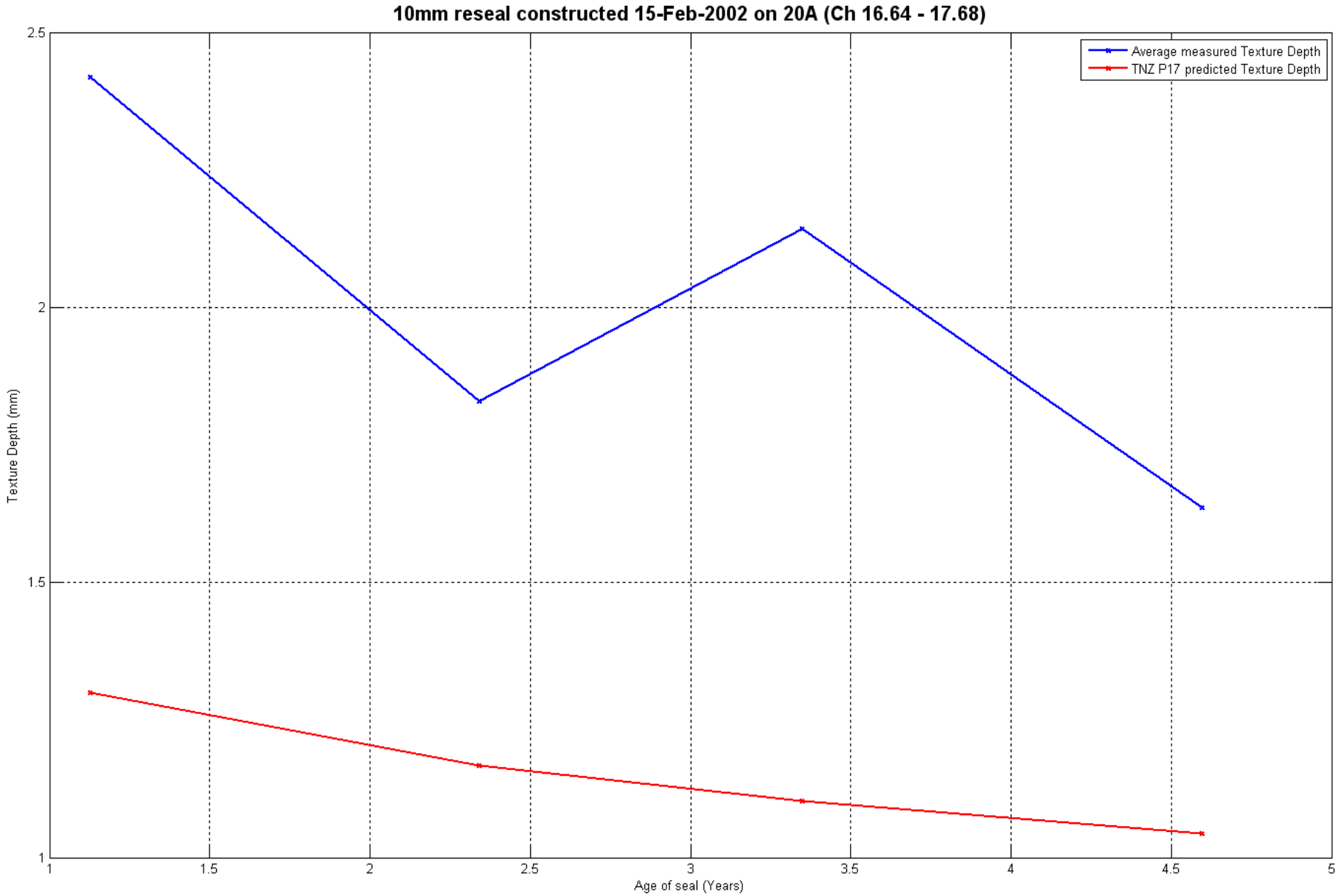

10mm reseal constructed 24-Feb-2003 on 20A (Ch 67.35 - 67.7)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.5
2
1.5
1
0
0.5
1
1.5
2
2.5
3
3.5
4

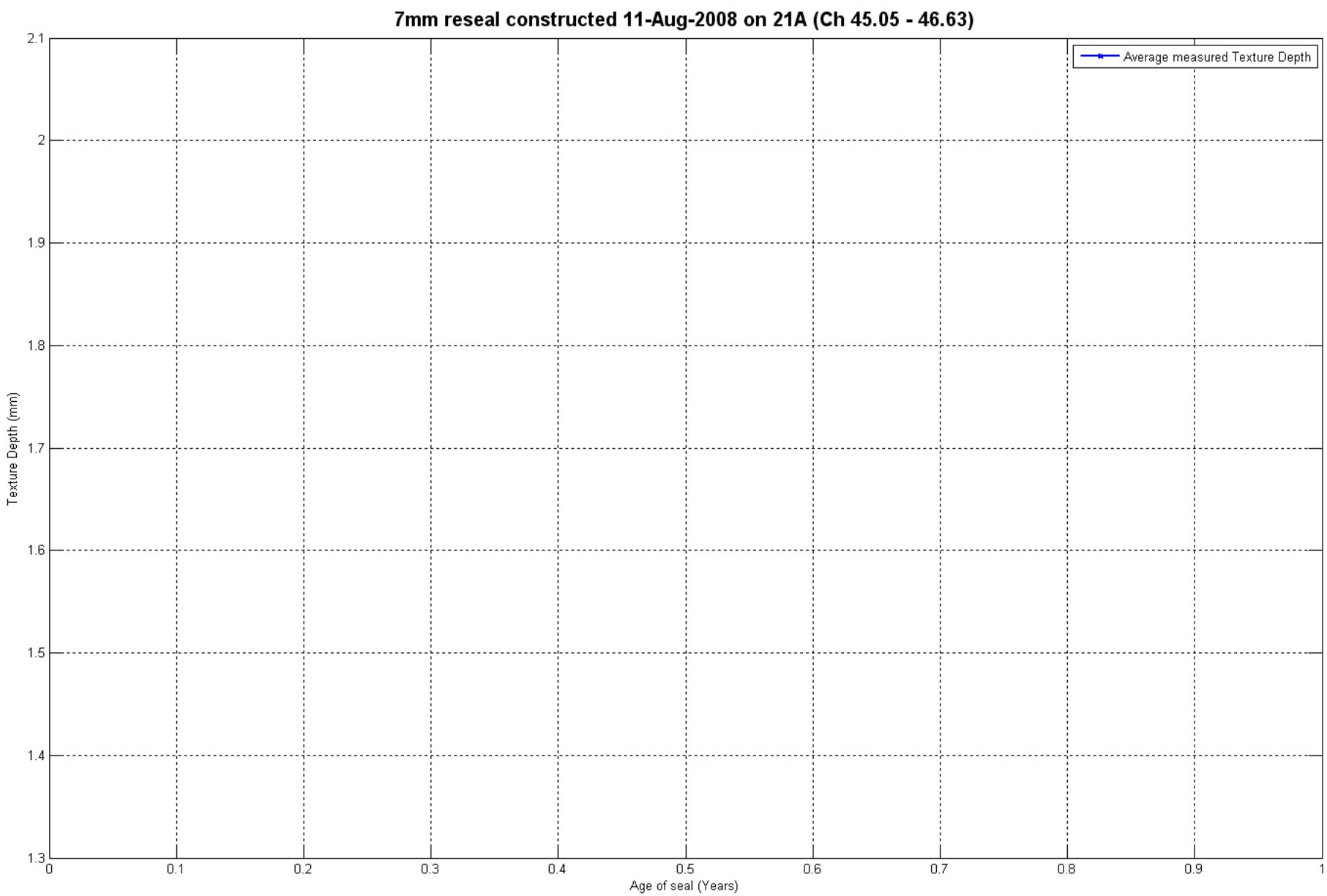

16mm reseal constructed 29-May-2008 on 20A (Ch 59.894 - 61.625)
Average measured Texture Depth
Texture Depth (mm)
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Age of seal (Years)

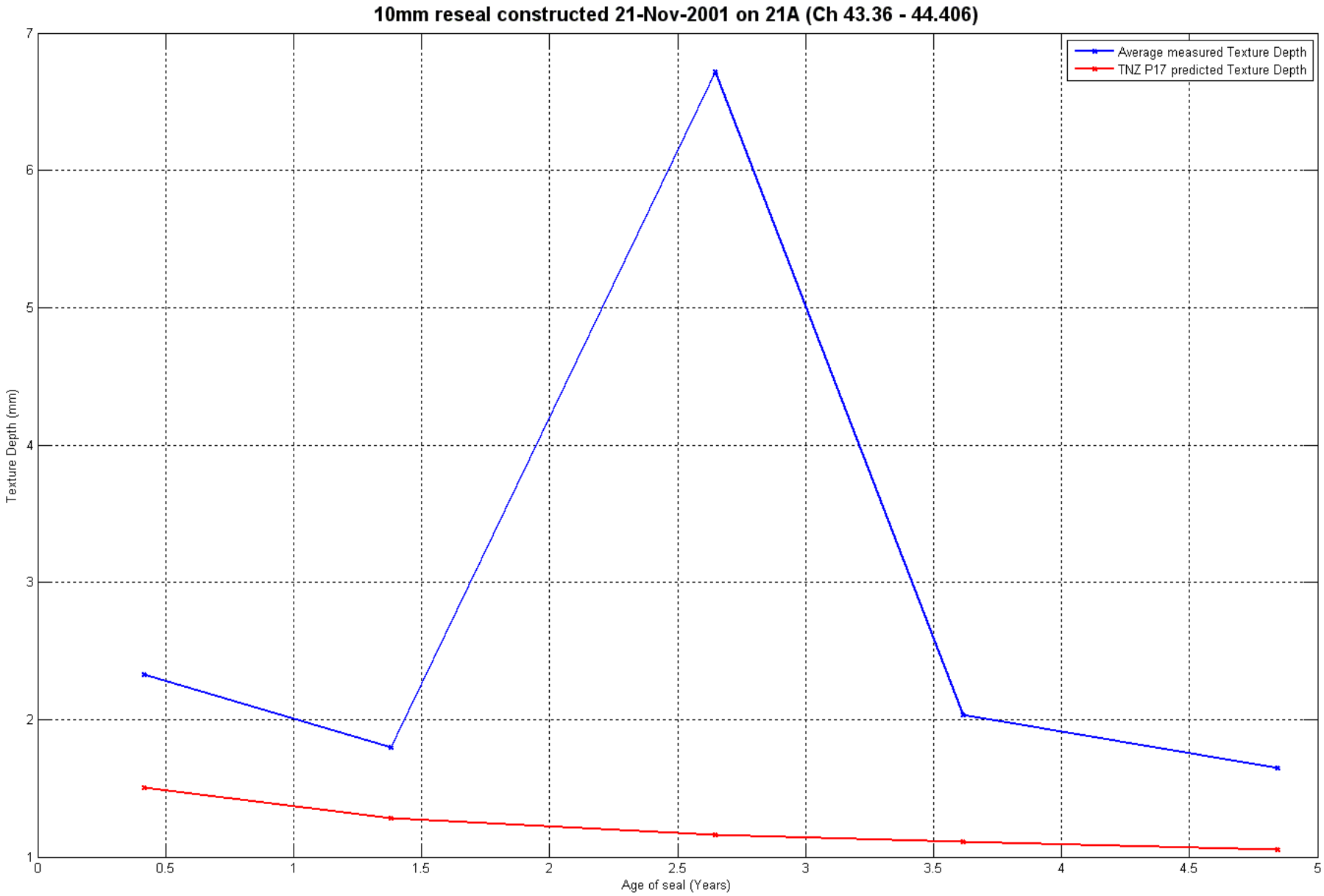

16mm reseal constructed 02-May-2004 on 20A (Ch 41.9 - 42.2)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
11
10
9
8
7
6
5
4
3
2
1
0
0.5
1
1.5
2
2.5

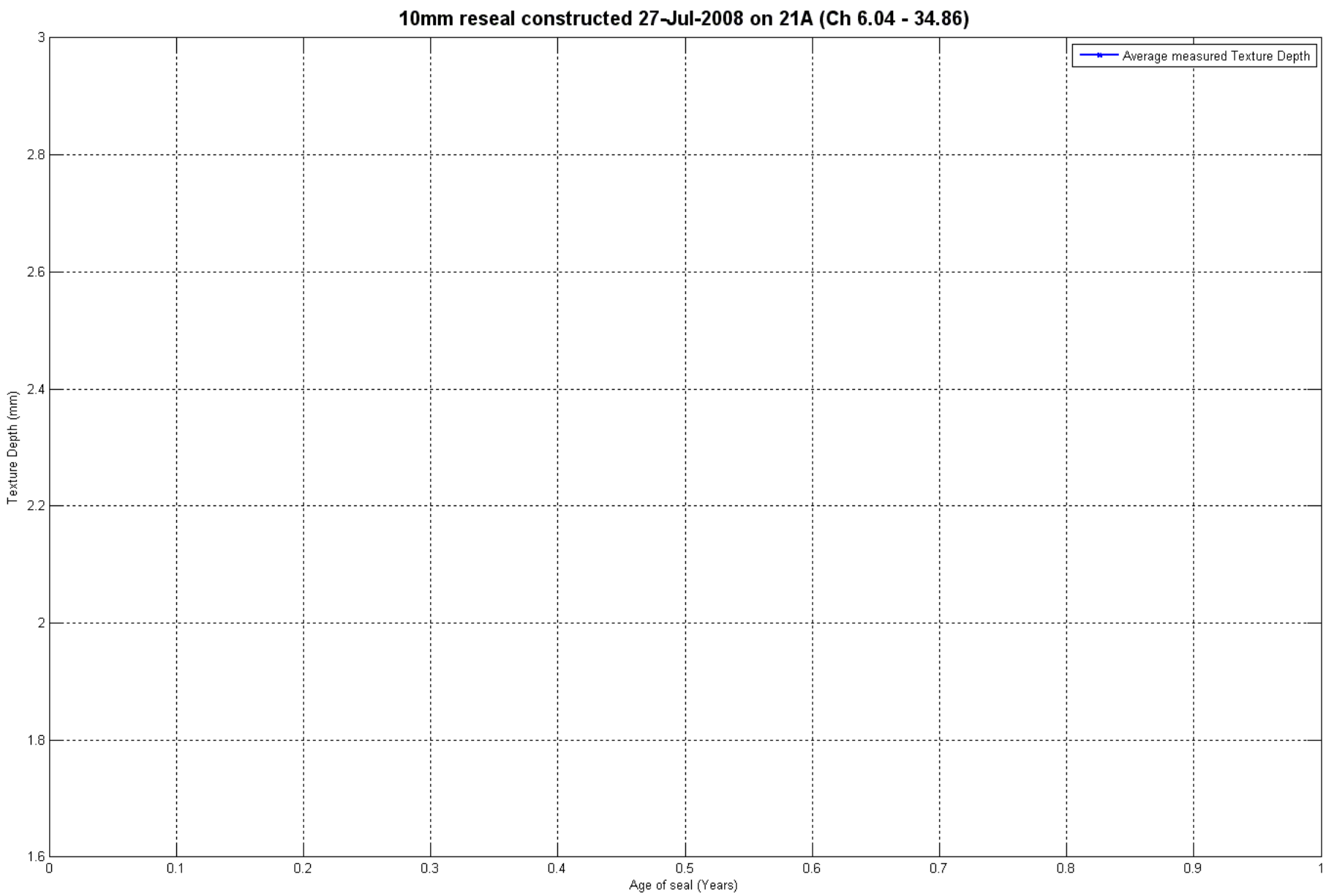

10mm reseal constructed 13-Dec-2001 on 20A (Ch 36.23 - 37.64)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
5
4.5
4
3.5
3
2.5
2
1.5
1
1
1.5
2
2.5
3
3.5
4
4.5
5

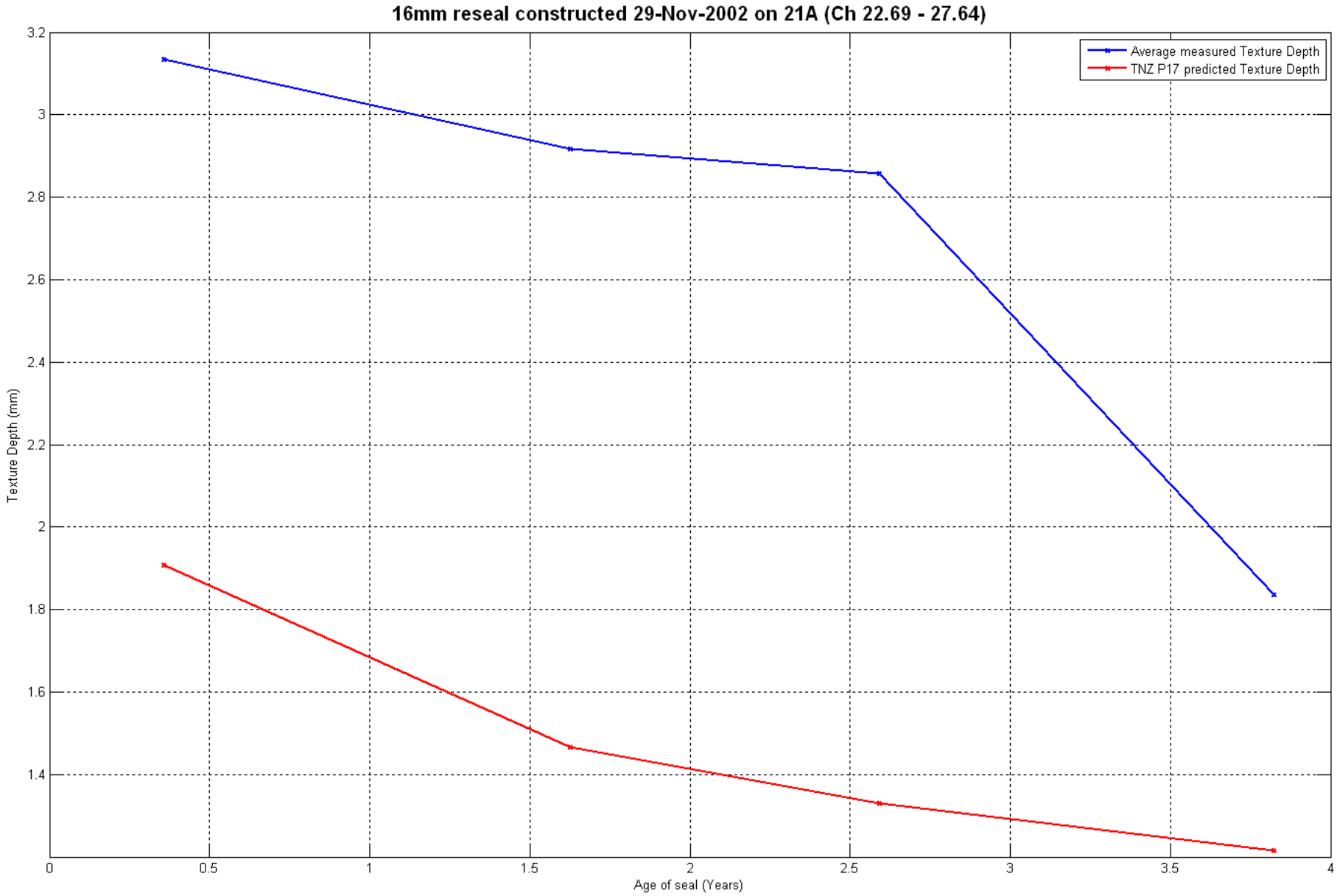

10mm reseal constructed 01-Sep-2001 on 20A (Ch 23.851 - 24.191)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.5
2
1.5
1
0
1
2
3
4
5
6


10mm reseal constructed 15-Feb-2002 on 20A (Ch 16.64 - 17.68)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
2.5
2
1.5
1
1
1.5
2
2.5
3
3.5
4
4.5
5


7mm reseal constructed 11-Aug-2008 on 21A (Ch 45.05 - 46.63)
Average measured Texture Depth
Texture Depth (mm)
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Age of seal (Years)


10mm reseal constructed 21-Nov-2001 on 21A (Ch 43.36 - 44.406)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
7
6
5
4
3
2
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


10mm reseal constructed 27-Jul-2008 on 21A (Ch 6.04 - 34.86)
Average measured Texture Depth
Texture Depth (mm)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Age of seal (Years)


16mm reseal constructed 29-Nov-2002 on 21A (Ch 22.69 - 27.64)
Average measured Texture Depth
TNZ P17 predicted Texture Depth
Texture Depth (mm)
Age of seal (Years)
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
0
0.5
1
1.5
2
2.5
3
3.5
4